US009328615B2

(12) **United States Patent**
Cooper

(10) **Patent No.:** **US 9,328,615 B2**
(45) **Date of Patent:** ***May 3, 2016**

(54) **ROTARY DEGASSERS AND COMPONENTS THEREFOR**

(71) Applicant: **Paul V. Cooper**, Chesterland, OH (US)

(72) Inventor: **Paul V. Cooper**, Chesterland, OH (US)

(73) Assignee: **Molten Metal Equipment Innovations, LLC**, Middlefield, OH (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/973,962**

(22) Filed: **Aug. 22, 2013**

(65) **Prior Publication Data**

US 2013/0343904 A1 Dec. 26, 2013

Related U.S. Application Data

(60) Division of application No. 12/878,984, filed on Sep. 9, 2010, now Pat. No. 8,524,146, which is a continuation-in-part of application No. 12/853,255, filed on Aug. 9, 2010, now Pat. No. 8,535,603.

(60) Provisional application No. 61/240,981, filed on Sep. 9, 2009, provisional application No. 61/232,384, filed on Aug. 7, 2009.

(51) **Int. Cl.**

C21C 7/00	(2006.01)
F01D 5/18	(2006.01)
C21C 1/06	(2006.01)
F16C 3/02	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ... ***F01D 5/18*** (2013.01); ***C21C 1/06*** (2013.01); ***F16C 3/02*** (2013.01); ***F16D 1/108*** (2013.01); ***F27D 3/16*** (2013.01); ***F27D 27/00*** (2013.01); *Y10T 403/25* (2015.01)

(58) **Field of Classification Search**

CPC F01D 5/18; F27D 27/00; F27D 27/005

USPC 266/235

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

35,604	A	6/1862	Guild
116,797	A	7/1871	Barnhart

(Continued)

FOREIGN PATENT DOCUMENTS

CA	683469	3/1964
CA	2115929	8/1992

(Continued)

OTHER PUBLICATIONS

English language translation (machine) of JP 05112837, May 1993.*

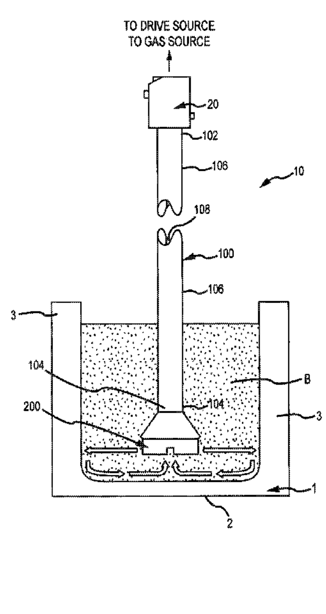
(Continued)

Primary Examiner — Scott Kastler
(74) *Attorney, Agent, or Firm* — Snell & Wilmer L.L.P.

(57) **ABSTRACT**

Disclosed are degassers, couplings, impeller shafts and impellers for use in molten metal. One such coupling transfers gas into an impeller shaft, the coupling having a smooth, tapered internal surface to align with a corresponding surface on the impeller shaft and help prevent gas leakage and to assist in preventing damage to the impeller shaft. Improved impellers for shearing and mixing gas are also disclosed, as is a degasser including one or more of these components.

17 Claims, 12 Drawing Sheets



(51) **Int. Cl.**

F16D 1/108	(2006.01)
F27D 3/16	(2006.01)
F27D 27/00	(2010.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

209,219	A	10/1878	Bookwalter
251,104	A	12/1881	Finch
364,804	A	6/1887	Cole
390,319	A	10/1888	Thomson
495,760	A	4/1893	Seitz
506,572	A	10/1893	Wagener
585,188	A	6/1897	Davis
757,932	A	4/1904	Jones
882,477	A	3/1908	Neumann
882,478	A	3/1908	Neumann
890,319	A	6/1908	Wells
898,499	A	9/1908	O'Donnell
909,774	A	1/1909	Flora
919,194	A	4/1909	Livingston
1,037,659	A	9/1912	Rembert
1,100,475	A	6/1914	Franckaerts
1,170,512	A	2/1916	Chapman
1,196,758	A	9/1916	Blair
1,304,068	A	5/1919	Krogh
1,331,997	A	2/1920	Neal
1,377,101	A	5/1921	Sparling
1,380,798	A	6/1921	Hansen et al.
1,439,365	A	12/1922	Hazell
1,454,967	A	5/1923	Gill
1,470,607	A	10/1923	Hazell
1,513,875	A	11/1924	Wilke
1,518,501	A	12/1924	Gill
1,522,765	A	1/1925	Wilke
1,526,851	A	2/1925	Hall
1,669,668	A	5/1928	Marshall
1,673,594	A	6/1928	Schmidt
1,697,202	A	1/1929	Nagle
1,717,969	A	6/1929	Goodner
1,718,396	A	6/1929	Wheeler
1,896,201	A	2/1933	Sterner-Rainer
1,988,875	A	1/1935	Saborio
2,013,455	A	9/1935	Baxter
2,038,221	A	4/1936	Kagi
2,090,162	A	8/1937	Tighe
2,091,677	A	8/1937	Fredericks
2,138,814	A	12/1938	Bressler
2,173,377	A	9/1939	Schultz, Jr. et al.
2,264,740	A	12/1941	Brown
2,280,979	A	4/1942	Rocke
2,290,961	A	7/1942	Heuer
2,300,688	A	11/1942	Nagle
2,304,849	A	12/1942	Ruthman
2,368,962	A	2/1945	Blom
2,383,424	A	8/1945	Stepanoff
2,423,655	A	7/1947	Mars et al.
2,488,447	A	11/1949	Tangen et al.
2,493,467	A	1/1950	Sunnen
2,515,097	A	7/1950	Schryber
2,515,478	A	7/1950	Tooley et al.
2,528,208	A	10/1950	Bonsack et al.
2,528,210	A	10/1950	Stewart
2,543,633	A	2/1951	Lamphere
2,566,892	A	9/1951	Jacobs
2,625,720	A	1/1953	Ross
2,626,086	A	1/1953	Forrest
2,676,279	A	4/1954	Wilson
2,677,609	A	5/1954	Moore et al.
2,698,583	A	1/1955	House et al.
2,714,354	A	8/1955	Farrand
2,762,095	A	9/1956	Pemetzrieder
2,768,587	A	10/1956	Corneil
2,775,348	A	12/1956	Williams
2,779,574	A	1/1957	Schneider
2,787,873	A	4/1957	Hadley
2,808,782	A	10/1957	Thompson et al.
2,809,107	A	10/1957	Russell
2,821,472	A	1/1958	Peterson et al.
2,824,520	A	2/1958	Bartels
2,832,292	A	4/1958	Edwards
2,839,006	A	6/1958	Mayo
2,853,019	A	9/1958	Thorton
2,865,295	A	12/1958	Nikolaus
2,865,618	A	12/1958	Abell
2,868,132	A	1/1959	Rittershofer
2,901,677	A	8/1959	Chessman et al.
2,906,632	A	9/1959	Nickerson
2,918,876	A	12/1959	Howe
2,948,524	A	8/1960	Sweeney et al.
2,958,293	A	11/1960	Pray, Jr.
2,978,885	A	4/1961	Davison
2,984,524	A	5/1961	Franzen
2,987,885	A	6/1961	Hodge
3,010,402	A	11/1961	King
3,015,190	A	1/1962	Arbeit
3,039,864	A	6/1962	Hess
3,044,408	A	7/1962	Mellott
3,048,384	A	8/1962	Sweeney et al.
3,070,393	A	12/1962	Silverberg et al.
3,092,030	A	6/1963	Wunder
3,099,870	A	8/1963	Seeler
3,128,327	A	4/1964	Upton
3,130,678	A	4/1964	Chenault
3,130,679	A	4/1964	Sence
3,171,357	A	3/1965	Egger
3,172,850	A	3/1965	Englesberg et al.
3,203,182	A	8/1965	Pohl
3,227,547	A	1/1966	Szekely
3,244,109	A	4/1966	Barske
3,251,676	A	5/1966	Johnson
3,255,702	A	6/1966	Gehrm
3,258,283	A	6/1966	Winberg et al.
3,272,619	A	9/1966	Sweeney et al.
3,289,473	A	12/1966	Louda
3,291,473	A	12/1966	Sweeney et al.
3,368,805	A	2/1968	Davey et al.
3,374,943	A	3/1968	Cervenka
3,400,923	A	9/1968	Howie et al.
3,417,929	A	12/1968	Secrest et al.
3,432,336	A	3/1969	Langrod
3,459,133	A	8/1969	Scheffler
3,459,346	A	8/1969	Tinnes
3,477,383	A	11/1969	Rawson et al.
3,487,805	A	1/1970	Satterthwaite
1,185,314	A	3/1970	London
3,512,762	A	5/1970	Umbricht
3,512,788	A	5/1970	Kilbane
3,532,445	A	10/1970	Scheffler et al.
3,561,885	A	2/1971	Lake
3,575,525	A	4/1971	Fox et al.
3,618,917	A	11/1971	Fredrikson
3,620,716	A	11/1971	Hess
3,650,730	A	3/1972	Derham et al.
3,689,048	A	9/1972	Foulard et al.
3,715,112	A	2/1973	Carbonnel
3,732,032	A	5/1973	Daneel
3,737,304	A	6/1973	Blayden
3,737,305	A	6/1973	Blayden et al.
3,743,263	A	7/1973	Szekely
3,743,500	A	7/1973	Foulard et al.
3,753,690	A	8/1973	Emley et al.
3,759,628	A	9/1973	Kempf
3,759,635	A	9/1973	Carter et al.
3,767,382	A	10/1973	Bruno et al.
3,776,660	A	12/1973	Anderson et al.
3,785,632	A	1/1974	Kraemer et al.
3,787,143	A	1/1974	Carbonnel et al.
3,799,522	A	3/1974	Brant et al.
3,799,523	A	3/1974	Seki
3,807,708	A	4/1974	Jones
3,814,400	A	6/1974	Seki
3,824,028	A	7/1974	Zenkner et al.
3,824,042	A	7/1974	Barnes et al.
3,836,280	A	9/1974	Koch

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,839,019 A 10/1974 Bruno et al.
3,844,972 A 10/1974 Tully, Jr. et al.
3,871,872 A 3/1975 Downing et al.
3,873,073 A 3/1975 Baum et al.
3,873,305 A 3/1975 Claxton et al.
3,881,039 A 4/1975 Baldieri et al.
3,886,992 A 6/1975 Maas et al.
3,915,594 A 10/1975 Nesseth
3,915,694 A 10/1975 Ando
3,941,588 A 3/1976 Dremann
3,941,589 A 3/1976 Norman et al.
3,954,134 A 5/1976 Maas et al.
3,958,979 A 5/1976 Valdo
3,958,981 A 5/1976 Forberg et al.
3,961,778 A 6/1976 Carbonnel et al.
3,966,456 A 6/1976 Ellenbaum et al.
3,967,286 A 6/1976 Andersson et al.
3,972,709 A 8/1976 Chia et al.
3,973,871 A 8/1976 Hance
3,984,234 A 10/1976 Claxton et al.
3,985,000 A 10/1976 Hartz
3,997,336 A 12/1976 van Linden et al.
4,003,560 A 1/1977 Carbonnel
4,008,884 A 2/1977 Fitzpatrick et al.
4,018,598 A 4/1977 Markus
4,052,199 A 10/1977 Mangalick
4,055,390 A 10/1977 Young
4,063,849 A 12/1977 Modianos
4,068,965 A 1/1978 Lichti
4,073,606 A 2/1978 Eller
4,091,970 A 5/1978 Kimiyama et al.
4,119,141 A 10/1978 Thut et al.
4,126,360 A 11/1978 Miller et al.
4,128,415 A 12/1978 van Linden et al.
4,169,584 A 10/1979 Mangalick
4,191,486 A 3/1980 Pelton
4,213,742 A 7/1980 Henshaw
4,242,039 A 12/1980 Villard et al.
4,244,423 A 1/1981 Thut et al.
4,286,985 A 9/1981 van Linden et al.
4,305,214 A 12/1981 Hurst
4,322,245 A 3/1982 Claxton
4,338,062 A 7/1982 Neal
4,347,041 A 8/1982 Cooper
4,351,514 A 9/1982 Koch
4,355,789 A 10/1982 Dolzhenkov et al.
4,356,940 A 11/1982 Ansorge
4,360,314 A 11/1982 Pennell
4,370,096 A 1/1983 Church
4,372,541 A 2/1983 Bocourt et al.
4,375,937 A 3/1983 Cooper
4,389,159 A 6/1983 Sarvanne
4,392,888 A 7/1983 Eckert et al.
4,410,299 A 10/1983 Shimoyama
4,419,049 A 12/1983 Gerboth et al.
4,456,424 A 6/1984 Araoka
4,470,846 A 9/1984 Dube
4,474,315 A 10/1984 Gilbert et al.
4,496,393 A 1/1985 Lustenberger
4,504,392 A 3/1985 Groteke
4,537,624 A 8/1985 Tenhover et al.
4,537,625 A 8/1985 Tenhover et al.
4,556,419 A 12/1985 Otsuka et al.
4,557,766 A 12/1985 Tenhover et al.
4,586,845 A 5/1986 Morris
4,592,700 A 6/1986 Toguchi et al.
4,594,052 A 6/1986 Niskanen
4,596,510 A 6/1986 Arneth
4,598,899 A 7/1986 Cooper
4,600,222 A 7/1986 Appling
4,607,825 A 8/1986 Briolle et al.
4,609,442 A 9/1986 Tenhover et al.
4,611,790 A 9/1986 Otsuka et al.
4,617,232 A 10/1986 Chandler et al.
4,634,105 A 1/1987 Withers et al.
4,640,666 A 2/1987 Sodergard
4,655,610 A 4/1987 Al-Jaroudi
4,673,434 A 6/1987 Withers et al.
4,684,281 A 8/1987 Patterson
4,685,822 A 8/1987 Pelton
4,696,703 A 9/1987 Henderson et al.
4,701,226 A 10/1987 Henderson et al.
4,702,768 A 10/1987 Areauz et al.
4,714,371 A 12/1987 Cuse
4,717,540 A 1/1988 McRae et al.
4,739,974 A 4/1988 Mordue
4,743,428 A 5/1988 McRae et al.
4,747,583 A 5/1988 Gordon et al.
4,767,230 A 8/1988 Leas, Jr.
4,770,701 A 9/1988 Henderson et al.
4,786,230 A 11/1988 Thut
4,802,656 A 2/1989 Hudault et al.
4,804,168 A 2/1989 Otsuka et al.
4,810,314 A 3/1989 Henderson et al.
4,834,573 A 5/1989 Asano et al.
4,842,227 A 6/1989 Harrington et al.
4,844,425 A 7/1989 Piras et al.
4,851,296 A 7/1989 Tenhover et al.
4,859,413 A 8/1989 Harris et al.
4,867,638 A 9/1989 Handtmann et al.
4,884,786 A 12/1989 Gillespie
4,898,367 A 2/1990 Cooper
4,908,060 A 3/1990 Duenkelmann
4,923,770 A 5/1990 Grasselli et al.
4,930,986 A 6/1990 Cooper
4,931,091 A 6/1990 Waite et al.
4,940,214 A 7/1990 Gillespie
4,940,384 A 7/1990 Amra et al.
4,954,167 A 9/1990 Cooper
4,973,433 A 11/1990 Gilbert et al.
4,986,736 A 1/1991 Kajiwara
5,015,518 A 5/1991 Sasaki et al.
5,025,198 A 6/1991 Mordue et al.
5,028,211 A 7/1991 Mordue et al.
5,029,821 A 7/1991 Bar-on et al.
5,078,572 A 1/1992 Amra et al.
5,080,715 A 1/1992 Provencher et al.
5,088,893 A 2/1992 Gilbert et al.
5,092,821 A 3/1992 Gilbert et al.
5,098,134 A 3/1992 Monckton
5,114,312 A 5/1992 Stanislao
5,126,047 A 6/1992 Martin et al.
5,131,632 A 7/1992 Olson
5,143,357 A 9/1992 Gilbert et al.
5,145,322 A 9/1992 Senior, Jr. et al.
5,152,631 A 10/1992 Bauer
5,154,652 A 10/1992 Ecklesdafer
5,158,440 A 10/1992 Cooper et al.
5,162,858 A 11/1992 Shoji et al.
5,165,858 A 11/1992 Gilbert et al.
5,177,304 A 1/1993 Nagel
5,191,154 A 3/1993 Nagel
5,192,193 A 3/1993 Cooper et al.
5,202,100 A 4/1993 Nagel et al.
5,203,681 A 4/1993 Cooper
5,209,641 A 5/1993 Hoglund et al.
5,215,448 A 6/1993 Cooper
5,268,020 A 12/1993 Claxton
5,286,163 A 2/1994 Amra et al.
5,298,233 A 3/1994 Nagel
5,301,620 A 4/1994 Nagel et al.
5,303,903 A 4/1994 Butler et al.
5,308,045 A 5/1994 Cooper
5,310,412 A 5/1994 Gilbert et al.
5,318,360 A 6/1994 Langer et al.
5,322,547 A 6/1994 Nagel et al.
5,324,341 A 6/1994 Nagel et al.
5,330,328 A 7/1994 Cooper
5,354,940 A 10/1994 Nagel
5,358,549 A 10/1994 Nagel et al.
5,358,697 A 10/1994 Nagel
5,364,078 A 11/1994 Pelton
5,369,063 A 11/1994 Gee et al.
5,388,633 A 2/1995 Mercer, II et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,395,405 A	3/1995	Nagel et al.	
5,399,074 A	3/1995	Nose et al.	
5,407,294 A	4/1995	Giannini	
5,411,240 A	5/1995	Rapp et al.	
5,425,410 A	6/1995	Reynolds	
5,431,551 A	7/1995	Aquino et al.	
5,435,982 A	7/1995	Wilkinson	
5,436,210 A	7/1995	Wilkinson et al.	
5,443,572 A	8/1995	Wilkinson et al.	
5,454,423 A	10/1995	Tsuchida et al.	
5,468,280 A	11/1995	Areaux	
5,470,201 A	11/1995	Gilbert et al.	
5,484,265 A	1/1996	Horvath et al.	
5,489,734 A	2/1996	Nagel et al.	
5,491,279 A	2/1996	Robert et al.	
5,495,746 A	3/1996	Sigworth	
5,505,143 A	4/1996	Nagel	
5,505,435 A	4/1996	Laszlo	
5,509,791 A	4/1996	Turner	
5,537,940 A	7/1996	Nagel et al.	
5,543,558 A	8/1996	Nagel et al.	
5,555,822 A	9/1996	Loewen et al.	
5,558,501 A	9/1996	Wang et al.	
5,558,505 A	9/1996	Mordue et al.	
5,571,486 A	11/1996	Robert et al.	
5,585,532 A	12/1996	Nagel	
5,586,863 A	12/1996	Gilbert et al.	
5,591,243 A	1/1997	Colussi et al.	
5,597,289 A	1/1997	Thut	
5,613,245 A	3/1997	Robert	
5,616,167 A	4/1997	Eckert	
5,622,481 A	4/1997	Thut	
5,629,464 A	5/1997	Bach et al.	
5,634,770 A	6/1997	Gilbert et al.	
5,640,706 A	6/1997	Nagel et al.	
5,640,707 A	6/1997	Nagel et al.	
5,640,709 A	6/1997	Nagel et al.	
5,655,849 A	8/1997	McEwen et al.	
5,660,614 A	8/1997	Waite et al.	
5,662,725 A	9/1997	Cooper	
5,676,520 A	10/1997	Thut	
5,678,244 A	10/1997	Shaw et al.	
5,678,807 A *	10/1997	Cooper	266/216
5,679,132 A	10/1997	Rauenzahn et al.	
5,685,701 A	11/1997	Chandler et al.	
5,690,888 A	11/1997	Robert	
5,695,732 A	12/1997	Sparks et al.	
5,716,195 A	2/1998	Thut	
5,717,149 A	2/1998	Nagel et al.	
5,718,416 A	2/1998	Flisakowski et al.	
5,735,668 A	4/1998	Klein	
5,735,935 A	4/1998	Areaux	
5,741,422 A	4/1998	Eichenmiller et al.	
5,744,117 A	4/1998	Wilkinson et al.	
5,745,861 A	4/1998	Bell et al.	
5,772,324 A	6/1998	Falk	
5,776,420 A	7/1998	Nagel	
5,785,494 A	7/1998	Vild et al.	
5,842,832 A	12/1998	Thut	
5,858,059 A	1/1999	Abramovich et al.	
5,863,314 A	1/1999	Morando	
5,866,095 A	2/1999	McGeever et al.	
5,875,385 A	2/1999	Stephenson et al.	
5,935,528 A	8/1999	Stephenson et al.	
5,944,496 A	8/1999	Cooper	
5,947,705 A	9/1999	Mordue et al.	
5,951,243 A	9/1999	Cooper	
5,961,285 A	10/1999	Meneice et al.	
5,963,580 A	10/1999	Eckert	
5,992,230 A	11/1999	Scarpa et al.	
5,993,726 A	11/1999	Huang	
5,993,728 A	11/1999	Vild	
6,019,576 A	2/2000	Thut	
6,027,685 A	2/2000	Cooper	
6,036,745 A	3/2000	Gilbert et al.	
6,074,455 A	6/2000	van Linden et al.	
6,082,965 A	7/2000	Morando	
6,093,000 A	7/2000	Cooper	
6,096,109 A	8/2000	Nagel et al.	
6,113,154 A	9/2000	Thut	
6,123,523 A	9/2000	Cooper	
6,152,691 A	11/2000	Thut	
6,168,753 B1	1/2001	Morando	
6,187,096 B1	2/2001	Thut	
6,199,836 B1	3/2001	Rexford et al.	
6,217,823 B1	4/2001	Vild et al.	
6,231,639 B1	5/2001	Eichenmiller	
6,250,881 B1	6/2001	Mordue et al.	
6,254,340 B1	7/2001	Vild et al.	
6,270,717 B1	8/2001	Tremblay et al.	
6,280,157 B1	8/2001	Cooper	
6,293,759 B1	9/2001	Thut	
6,303,074 B1	10/2001	Cooper	
6,345,964 B1	2/2002	Cooper	
6,354,796 B1	3/2002	Morando	
6,358,467 B1	3/2002	Mordue	
6,364,930 B1	4/2002	Kos	
6,371,723 B1	4/2002	Grant et al.	
6,398,525 B1	6/2002	Cooper	
6,439,860 B1	8/2002	Greer	
6,451,247 B1	9/2002	Mordue et al.	
6,457,940 B1	10/2002	Lehman	
6,457,950 B1	10/2002	Cooper et al.	
6,464,458 B2	10/2002	Vild et al.	
6,464,459 B2	10/2002	Illingworth	
6,497,559 B1	12/2002	Grant	
6,500,228 B1	12/2002	Klingensmith et al.	
6,503,292 B2	1/2003	Klingensmith et al.	
6,524,066 B2	2/2003	Thut	
6,533,535 B2	3/2003	Thut	
6,551,060 B2	4/2003	Mordue et al.	
6,562,286 B1	5/2003	Lehman	
6,656,415 B2	12/2003	Kos	
6,679,936 B2	1/2004	Quackenbush	
6,689,310 B1	2/2004	Cooper	
6,709,234 B2	3/2004	Gilbert et al.	
6,723,276 B1	4/2004	Cooper	
6,805,834 B2	10/2004	Thut	
6,843,640 B2	1/2005	Mordue et al.	
6,848,497 B2	2/2005	Sale et al.	
6,869,271 B2	3/2005	Gilbert et al.	
6,869,564 B2	3/2005	Gilbert et al.	
6,881,030 B2	4/2005	Thut	
6,887,424 B2	5/2005	Ohno et al.	
6,887,425 B2	5/2005	Mordue et al.	
6,902,696 B2	6/2005	Klingensmith et al.	
7,037,462 B2	5/2006	Klingensmith et al.	
7,083,758 B2	8/2006	Tremblay	
7,131,482 B2	11/2006	Vincent et al.	
7,157,043 B2	1/2007	Neff	
7,279,128 B2	10/2007	Kennedy et al.	
7,326,028 B2	2/2008	Morando	
7,402,276 B2	7/2008	Cooper	
7,470,392 B2	12/2008	Cooper	
7,476,357 B2	1/2009	Thut	
7,497,988 B2	3/2009	Thut	
7,507,367 B2	3/2009	Cooper	
7,543,605 B1	6/2009	Morando	
7,731,891 B2	6/2010	Cooper	
7,906,068 B2	3/2011	Cooper	
8,110,141 B2	2/2012	Cooper	
8,137,023 B2	3/2012	Greer	
8,142,145 B2	3/2012	Thut	
8,178,037 B2	5/2012	Cooper	
8,328,540 B2	12/2012	Wang	
8,333,921 B2	12/2012	Thut	
8,337,746 B2	12/2012	Cooper	
8,361,379 B2	1/2013	Cooper	
8,366,993 B2	2/2013	Cooper	
8,440,135 B2	5/2013	Cooper	
8,449,814 B2	5/2013	Cooper	
8,469,081 B2	6/2013	Cooper	
8,475,594 B2	7/2013	Bright et al.	
8,475,708 B2	7/2013	Cooper	

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,480,950	B2	7/2013	Jetten et al.	
8,501,084	B2	8/2013	Cooper	
8,524,146	B2	9/2013	Cooper	
8,529,828	B2	9/2013	Cooper	
8,535,603	B2 *	9/2013	Cooper	266/235
8,580,218	B2	11/2013	Turenne et al.	
8,613,884	B2	12/2013	Cooper	
8,714,914	B2	5/2014	Cooper	
8,753,563	B2	6/2014	Cooper	
8,840,359	B2	9/2014	Vick et al.	
8,899,932	B2	12/2014	Tetkoskie et al.	
8,915,830	B2	12/2014	March et al.	
8,920,680	B2	12/2014	Mao	
9,011,761	B2	4/2015	Cooper	
9,017,597	B2	4/2015	Cooper	
9,034,244	B2	5/2015	Cooper	
9,156,087	B2	10/2015	Cooper	
9,205,490	B2	12/2015	Cooper	
2001/0000465	A1	4/2001	Thut	
2002/0146313	A1	10/2002	Thut	
2002/0185794	A1	12/2002	Vincent	
2003/0047850	A1	3/2003	Areaux	
2003/0082052	A1	5/2003	Gilbert et al.	
2003/0201583	A1	10/2003	Klingensmith	
2004/0050525	A1	3/2004	Kennedy et al.	
2004/0076533	A1	4/2004	Cooper	
2004/0115079	A1	6/2004	Cooper	
2004/0262825	A1	12/2004	Cooper	
2005/0013713	A1	1/2005	Cooper	
2005/0013714	A1	1/2005	Cooper	
2005/0013715	A1	1/2005	Cooper	
2005/0053499	A1	3/2005	Cooper	
2005/0077730	A1	4/2005	Thut	
2005/0116398	A1	6/2005	Tremblay	
2006/0180963	A1	8/2006	Thut	
2007/0253807	A1	11/2007	Cooper	
2008/0213111	A1	9/2008	Cooper	
2008/0230966	A1	9/2008	Cooper	
2008/0253905	A1	10/2008	Morando et al.	
2008/0304970	A1	12/2008	Cooper	
2008/0314548	A1	12/2008	Cooper	
2009/0054167	A1	2/2009	Cooper	
2009/0269191	A1	10/2009	Cooper	
2010/0104415	A1	4/2010	Morando	
2011/0133374	A1	6/2011	Cooper	
2011/0140319	A1	6/2011	Cooper	
2011/0142603	A1	6/2011	Cooper	
2011/0142606	A1	6/2011	Cooper	
2011/0148012	A1	6/2011	Cooper	
2011/0163486	A1	7/2011	Cooper	
2011/0210232	A1	9/2011	Cooper	
2011/0220771	A1	9/2011	Cooper	
2011/0303706	A1	12/2011	Cooper	
2012/0003099	A1	1/2012	Tetkoskie	
2012/0163959	A1	6/2012	Morando	
2013/0105102	A1	5/2013	Cooper	
2013/0142625	A1	6/2013	Cooper	
2013/0214014	A1	8/2013	Cooper	
2013/0224038	A1	8/2013	Tetkoskie	
2013/0292426	A1	11/2013	Cooper	
2013/0292427	A1	11/2013	Cooper	
2013/0299524	A1	11/2013	Cooper	
2013/0299525	A1	11/2013	Cooper	
2013/0306687	A1	11/2013	Cooper	
2013/0334744	A1	12/2013	Tremblay	
2013/0343904	A1 *	12/2013	Cooper	416/90 R
2014/0041252	A1	2/2014	Vild et al.	
2014/0044520	A1	2/2014	Tipton	
2014/0083253	A1	3/2014	Lutes et al.	
2014/0210144	A1	7/2014	Torres et al.	
2014/0232048	A1	8/2014	Howitt et al.	
2014/0252701	A1	9/2014	Cooper	
2014/0261800	A1	9/2014	Cooper	
2014/0265068	A1	9/2014	Cooper	
2014/0271219	A1	9/2014	Cooper	
2014/0363309	A1	12/2014	Henderson et al.	
2015/0192364	A1	7/2015	Cooper	
2015/0217369	A1	8/2015	Cooper	
2015/0219112	A1	8/2015	Cooper	
2015/0219113	A1	8/2015	Cooper	
2015/0219114	A1	8/2015	Cooper	
2015/0224574	A1	8/2015	Cooper	
2015/0252807	A1	9/2015	Cooper	
2015/0285557	A1	10/2015	Cooper	
2015/0285558	A1	10/2015	Cooper	
2015/0323256	A1	11/2015	Cooper	
2015/0328682	A1	11/2015	Cooper	
2015/0328683	A1	11/2015	Cooper	
2016/0031007	A1	2/2016	Cooper	
2016/0040265	A1	2/2016	Cooper	
2016/0047602	A1	2/2016	Cooper	

FOREIGN PATENT DOCUMENTS

CA	2244251		12/1996
CA	2305865		2/2000
CA	2176475		7/2005
CH	392268		9/1965
DE	1800446		12/1969
EP	0168250		1/1986
EP	0665378		2/1995
EP	1019635		6/2006
GB	942648		11/1963
GB	1185314		3/1970
GB	2217784		3/1989
JP	58048796		3/1983
JP	63104773		5/1988
JP	05112837	A *	5/1993
MX	227385		4/2005
NO	90756		1/1959
RU	416401		2/1974
RU	773312		10/1980
WO	WO9808990		3/1998
WO	WO9825031		6/1998
WO	WO0009889		2/2000
WO	WO0212147		2/2002
WO	WO2004029307		4/2004
WO	2014055082		4/2014
WO	2014150503		9/2014
WO	2014185971		11/2014

OTHER PUBLICATIONS

US 5,961,265, 10/1999, Meneice et al. (withdrawn).

USPTO; Notice of Reissue Examination Certificate dated Aug. 27, 2001 in U.S. Appl. No. 90/005,910.

Response to Final Office Action and Request for Continued Examination for U.S. Appl. No. 09/275,627, Including Declarations of Haynes and Johnson, Apr. 16, 2001.

Document No. 504217: Excerpts from Pyrotek Inc.'s Motion for Summary Judgment of Invalidity and Unenforceability of U.S. Pat. No. 7,402,276, Oct. 2, 2009.

Document No. 505026: Excerpts from MMEI's Response to Pyrotek's Motion for Summary Judgment of Invalidity or Enforceability of U.S. Pat. No. 7,402,276, Oct. 9, 2009.

Document No. 507689: Excerpts from MMEI's Pre-Hearing Brief and Supplemental Motion for Summary Judgment of Infringement of Claims 3-4, 15, 17-20, 26 and 28-29 of the '074 Patent and Motion for Reconsideration of the Validity of Claims 7-9 of the '276 Patent, Nov. 4, 2009.

Document No. 517158: Excerpts from "Reasoned Award," Feb. 19, 2010.

Document No. 525055: Excerpts from "Molten Metal Equipment Innovations, Inc.'s Reply Brief in Support of Application to Confirm Arbitration Award and Opposition to Motion to Vacate," May 12, 2010.

USPTO; Office Action dated Feb. 23, 1996 in U.S. Appl. No. 08/439,739.

USPTO; Office Action dated Aug. 15, 1996 in U.S. Appl. No. 08/439,739.

USPTO; Advisory Action dated Nov. 18, 1996 in U.S. Appl. No. 08/439,739.

(56) **References Cited**

OTHER PUBLICATIONS

USPTO; Advisory Action dated Dec. 9, 1996 in U.S. Appl. No. 08/439,739.
USPTO; Notice of Allowance dated Jan. 17, 1997 in U.S. Appl. No. 08/439,739.
USPTO; Office Action dated Jul. 22, 1996 in U.S. Appl. No. 08/489,962.
USPTO; Office Action dated Jan. 6, 1997 in U.S. Appl. No. 08/489,962.
USPTO; Interview Summary dated Mar. 4, 1997 in U.S. Appl. No. 08/489,962.
USPTO; Notice of Allowance dated Mar. 27, 1997 in U.S. Appl. No. 08/489,962.
USPTO; Office Action dated Sep. 23, 1998 in U.S. Appl. No. 08/759,780.
USPTO; Interview Summary dated Dec. 30, 1998 in U.S. Appl. No. 08/789,780.
USPTO; Notice of Allowance dated Mar. 17, 1999 in U.S. Appl. No. 08/789,780.
USPTO; Office Action dated Jul. 23, 1998 in U.S. Appl. No. 08/889,882.
USPTO; Office Action dated Jan. 21, 1999 in U.S. Appl. No. 08/889,882.
USPTO; Notice of Allowance dated Mar. 17, 1999 in U.S. Appl. No. 08/889,882.
USPTO; Office Action dated Feb. 26, 1999 in U.S. Appl. No. 08/951,007.
USPTO; Interview Summary dated Mar. 15, 1999 in U.S. Appl. No. 08/951,007.
USPTO; Office Action dated May 17, 1999 in U.S. Appl. No. 08/951,007.
USPTO; Notice of Allowance dated Aug. 27, 1999 in U.S. Appl. No. 08/951,007.
USPTO; Office Action dated Dec. 23, 1999 in U.S. Appl. No. 09/132,934.
USPTO; Notice of Allowance dated Mar. 9, 2000 in U.S. Appl. No. 09/132,934.
USPTO; Office Action dated Jan. 7, 2000 in U.S. Appl. No. 09/152,168.
USPTO; Notice of Allowance dated Aug. 7, 2000 in U.S. Appl. No. 09/152,168.
USPTO; Office Action dated Sep. 29, 1999 in U.S. Appl. No. 09/275,627.
USPTO; Office Action dated May 22, 2000 in U.S. Appl. No. 09/275,627.
USPTO; Office Action dated Nov. 14, 2000 in U.S. Appl. No. 09/275,627.
USPTO; Office Action dated May 21, 2001 in U.S. Appl. No. 09/275,627.
USPTO; Notice of Allowance dated Aug. 31, 2001 in U.S. Appl. No. 09/275,627.
USPTO; Office Action dated Jun. 15, 2000 in U.S. Appl. No. 09/312,361.
USPTO; Notice of Allowance dated Jan. 29, 2001 in U.S. Appl. No. 09/312,361.
USPTO; Office Action dated Jun. 22, 2001 in U.S. Appl. No. 09/569,461.
USPTO; Office Action dated Oct. 12, 2001 in U.S. Appl. No. 09/569,461.
USPTO; Office Action dated May 3, 2002 in U.S. Appl. No. 09/569,461.
USPTO; Advisory Action dated May 14, 2002 in U.S. Appl. No. 09/569,461.
USPTO; Office Action dated Dec. 4, 2002 in U.S. Appl. No. 09/569,461.
USPTO; Interview Summary dated Jan. 14, 2003 in U.S. Appl. No. 09/569,461.
USPTO; Notice of Allowance dated Jun. 24, 2003 in U.S. Appl. No. 09/569,461.
USPTO; Office Action dated Nov. 21, 2000 in U.S. Appl. No. 09/590,108.
USPTO; Office Action dated May 22, 2001 in U.S. Appl. No. 09/590,108.
USPTO; Notice of Allowance dated Sep. 10, 2001 in U.S. Appl. No. 09/590,108.
USPTO; Office Action dated Jan. 30, 2002 in U.S. Appl. No. 09/649,190.
USPTO; Office Action dated Oct. 4, 2002 in U.S. Appl. No. 09/649,190.
USPTO; Office Action dated Apr. 18, 2003 in U.S. Appl. No. 09/649,190.
USPTO; Notice of Allowance dated Nov. 21, 2003 in U.S. Appl. No. 09/649,190.
USPTO; Office Action dated Jun. 7, 2006 in U.S. Appl. No. 10/619,405.
USPTO; Final Office Action dated Feb. 20, 2007 in U.S. Appl. No. 10/619,405.
USPTO; Office Action dated Oct. 9, 2007 in U.S. Appl. No. 10/619,405.
USPTO; Final Office Action dated May 29, 2008 in U.S. Appl. No. 10/619,405.
USPTO; Interview Summary Aug. 22, 2008 in U.S. Appl. No. 10/619,405.
USPTO; Ex Parte Quayle dated Sep. 12, 2008 in U.S. Appl. No. 10/619,405.
USPTO; Interview Summary dated Oct. 16, 2008 in U.S. Appl. No. 10/619,405.
USPTO; Notice of Allowance dated Nov. 14, 2008 in U.S. Appl. No. 10/619,405.
USPTO; Office Action dated Mar. 20, 2006 in U.S. Appl. No. 10/620,318.
USPTO; Office Action dated Nov. 16, 2006 in U.S. Appl. No. 10/620,318.
USPTO; Final Office Action dated Jul. 25, 2007 in U.S. Appl. No. 10/620,318.
USPTO; Office Action dated Feb. 12, 2008 in U.S. Appl. No. 10/620,318.
USPTO; Final Office Action dated Oct. 16, 2008 in U.S. Appl. No. 10/620,318.
USPTO; Office Action dated Feb. 25, 2009 in U.S. Appl. No. 10/620,318.
USPTO; Final Office Action dated Oct. 8, 2009 in U.S. Appl. No. 10/620,318.
USPTO; Notice of Allowance Jan. 26, 2010 in U.S. Appl. No. 10/620,318.
USPTO; Office Action dated Nov. 15, 2007 in U.S. Appl. No. 10/773,101.
USPTO; Office Action dated Jun. 27, 2006 in U.S. Appl. No. 10/773,102.
USPTO; Final Office Action dated Mar. 6, 2007 in U.S. Appl. No. 10/773,102.
USPTO; Office Action dated Oct. 11, 2007 in U.S. Appl. No. 10/773,102.
USPTO; Interview Summary dated Mar. 18, 2008 in U.S. Appl. No. 10/773,102.
USPTO; Notice of Allowance dated Apr. 18, 2008 in U.S. Appl. No. 10/773,102.
USPTO; Office Action dated Jul. 24, 2006 in U.S. Appl. No. 10/773,105.
USPTO; Office Action dated Oct. 9, 2007 in U.S. Appl. No. 10/773,105.
USPTO; Interview Summary dated Jan. 25, 2008 in U.S. Appl. No. 10/773,105.
USPTO; Office Action dated May 19, 2008 in U.S. Appl. No. 10/773,105.
USPTO; Interview Summary dated Jul. 21, 2008 in U.S. Appl. No. 10/773,105.
USPTO; Notice of Allowance dated Sep. 29, 2008 in U.S. Appl. No. 10/773,105.
USPTO; Office Action dated Jan. 31, 2008 in U.S. Appl. No. 10/773,118.

(56) **References Cited**

OTHER PUBLICATIONS

USPTO; Final Office Action dated Aug. 18, 2008 in U.S. Appl. No. 10/773,118.
USPTO; Interview Summary dated Oct. 16, 2008 in U.S. Appl. No. 10/773,118.
USPTO; Office Action dated Dec. 15, 2008 in U.S. Appl. No. 10/773,118.
USPTO; Final Office Action dated May 1, 2009 in U.S. Appl. No. 10/773,118.
USPTO; Office Action dated Jul. 27, 2009 in U.S. Appl. No. 10/773,118.
USPTO; Final Office Action dated Feb. 2, 2010 in U.S. Appl. No. 10/773,118.
USPTO; Interview Summary dated Jun. 4, 2010 in U.S. Appl. No. 10/773,118.
USPTO; Ex Parte Quayle Action dated Aug. 25, 2010 in U.S. Appl. No. 10/773,118.
USPTO; Notice of Allowance dated Nov. 5, 2010 in U.S. Appl. No. 10/773,118.
USPTO; Office Action dated Mar. 16, 2005 in U.S. Appl. No. 10/827,941.
USPTO; Final Office Action dated Nov. 7, 2005 in U.S. Appl. No. 10/827,941.
USPTO; Office Action dated Jul. 12, 2006 in U.S. Appl. No. 10/827,941.
USPTO; Final Office Action dated Mar. 8, 2007 in U.S. Appl. No. 10/827,941.
USPTO; Office Action dated Oct. 29, 2007 in U.S. Appl. No. 10/827,941.
USPTO; Office Action dated Sep. 26, 2008 in U.S. Appl. No. 11/413,982.
USPTO; Office Action dated Dec. 11, 2009 in U.S. Appl. No. 11/766,617.
USPTO; Office Action dated Mar. 8, 2010 in U.S. Appl. No. 11/766,617.
USPTO; Final Office Action dated Sep. 20, 2010 in U.S. Appl. No. 11/766,617.
USPTO; Office Action dated Mar. 1, 2011 in U.S. Appl. No. 11/766,617.
USPTO; Final Office Action dated Sep. 22, 2011 in U.S. Appl. No. 11/766,617.
USPTO; Office Action dated Jan. 27, 2012 in U.S. Appl. No. 11/766,617.
USPTO; Notice of Allowance dated May 15, 2012 in U.S. Appl. No. 11/766,617.
USPTO; Supplemental Notice of Allowance dated Jul. 31, 2012 in U.S. Appl. No. 11/766,617.
USPTO; Notice of Allowance dated Aug. 24, 2012 in U.S. Appl. No. 11/766,617.
USPTO; Final Office Action dated Oct. 14, 2008 in U.S. Appl. No. 12/111,835.
USPTO; Office Action dated May 15, 2009 in U.S. Appl. No. 12/111,835.
USPTO; Office Action dated Mar. 31, 2009 in U.S. Appl. No. 12/120,190.
USPTO; Final Office Action dated Dec. 4, 2009 in U.S. Appl. No. 12/120,190.
USPTO; Office Action dated Jun. 28, 2010 in U.S. Appl. No. 12/120,190.
USPTO; Final Office Action dated Jan. 6, 2011 in U.S. Appl. No. 12/120,190.
USPTO; Office Action dated Jun. 27, 2011 in U.S. Appl. No. 12/120,190.
USPTO; Final Office Action dated Nov. 28, 2011 in U.S. Appl. No. 12/120,190.
USPTO; Notice of Allowance dated Feb. 6, 2012 in U.S. Appl. No. 12/120,190.
USPTO; Office Action dated Nov. 3, 2008 in U.S. Appl. No. 12/120,200.
USPTO; Final Office Action dated May 28, 2009 in U.S. Appl. No. 12/120,200.
USPTO; Office Action dated Dec. 18, 2009 in U.S. Appl. No. 12/120,200.
USPTO; Final Office Action dated Jul. 9, 2010 in U.S. Appl. No. 12/120,200.
USPTO; Office Action dated Jan. 21, 2011 in U.S. Appl. No. 12/120,200.
USPTO; Final Office Action dated Jul. 26, 2011 in U.S. Appl. No. 12/120,200.
USPTO; Final Office Action dated Feb. 3, 2012 in U.S. Appl. No. 12/120,200.
USPTO; Notice of Allowance dated Jan. 17, 2013 in U.S. Appl. No. 12/120,200.
USPTO; Office Action dated Jun. 16, 2009 in U.S. Appl. No. 12/146,770.
USPTO; Final Office Action dated Feb. 24, 2010 in U.S. Appl. No. 12/146,770.
USPTO; Office Action dated Jun. 9, 2010 in U.S. Appl. No. 12/146,770.
USPTO; Office Action dated Nov. 18, 2010 in U.S. Appl. No. 12/146,770.
USPTO; Final Office Action dated Apr. 4, 2011 in U.S. Appl. No. 12/146,770.
USPTO; Notice of Allowance dated Aug. 22, 2011 in U.S. Appl. No. 12/146,770.
USPTO; Notice of Allowance dated Nov. 1, 2011 in U.S. Appl. No. 12/146,770.
USPTO; Office Action dated Apr. 27, 2009 in U.S. Appl. No. 12/146,788.
USPTO; Final Office Action dated Oct. 15, 2009 in U.S. Appl. No. 12/146,788.
USPTO; Office Action dated Feb. 16, 2010 in U.S. Appl. No. 12/146,788.
USPTO; Final Office Action dated Jul. 13, 2010 in U.S. Appl. No. 12/146,788.
USPTO; Office Action dated Apr. 19, 2011 in U.S. Appl. No. 12/146,788.
USPTO; Notice of Allowance dated Aug. 19, 2011 in U.S. Appl. No. 12/146,788.
USPTO; Office Action dated Apr. 13, 2009 in U.S. Appl. No. 12/264,416.
USPTO; Final Office Action dated Oct. 8, 2009 in U.S. Appl. No. 12/264,416.
USPTO; Office Action dated Feb. 1, 2010 in U.S. Appl. No. 12/264,416.
USPTO; Final Office Action dated Jun. 30, 2010 in U.S. Appl. No. 12/264,416.
USPTO; Office Action dated Mar. 17, 2011 in U.S. Appl. No. 12/264,416.
USPTO; Final Office Action dated Jul. 7, 2011 in U.S. Appl. No. 12/264,416.
USPTO; Office Action dated Nov. 4, 2011 in U.S. Appl. No. 12/264,416.
USPTO; Final Office Action dated Jun. 8, 2012 in U.S. Appl. No. 12/264,416.
USPTO; Office Action dated Nov. 28, 2012 in U.S. Appl. No. 12/264,416.
USPTO; Ex Parte Quayle dated Apr. 3, 2013 in U.S. Appl. No. 12/264,416.
USPTO; Notice of Allowance dated Jun. 23, 2013 in U.S. Appl. No. 12/264,416.
USPTO; Office Action dated May 22, 2009 in U.S. Appl. No. 12/369,362.
USPTO; Final Office Action dated Dec. 14, 2009 in U.S. Appl. No. 12/369,362.
USPTO; Final Office Action dated Jun. 11, 2010 in U.S. Appl. No. 12/395,430.
USPTO; Office Action dated Nov. 24, 2010 in U.S. Appl. No. 12/395,430.
USPTO; Final Office Action dated Apr. 6, 2011 in U.S. Appl. No. 12/395,430.

(56) **References Cited**

OTHER PUBLICATIONS

USPTO; Office Action dated Aug. 18, 2011 in U.S. Appl. No. 12/395,430.
USPTO; Final Office Action dated Dec. 13, 2011 in U.S. Appl. No. 12/395,430.
USPTO; Advisory Action dated Feb. 22, 2012 in U.S. Appl. No. 12/395,430.
USPTO; Notice of Allowance dated Sep. 20, 2012 in U.S. Appl. No. 12/395,430.
USPTO; Office Action dated Sep. 29, 2010 in U.S. Appl. No. 12/758,509.
USPTO; Final Office Action dated May 11, 2011 in U.S. Appl. No. 12/758,509.
USPTO; Office Action dated Feb. 1, 2012 in U.S. Appl. No. 12/853,201.
USPTO; Final Office Action dated Jul. 3, 2012 in U.S. Appl. No. 12/853,201.
USPTO; Notice of Allowance dated Jan. 31, 2013 in U.S. Appl. No. 12/853,201.
USPTO; Office Action dated Jan. 3, 2013 in U.S. Appl. No. 12/853,238.
USPTO; Office Action dated Dec. 18, 2013 in U.S. Appl. No. 12/853,238.
USPTO; Final Office Action dated Jun. 19, 2014 in U.S. Appl. No. 12/853,238.
USPTO; Office Action dated Feb. 27, 2012 in U.S. Appl. No. 12/853,253.
USPTO; Ex Parte Quayle Action dated Jun. 27, 2012 in U.S. Appl. No. 12/853,253.
USPTO; Notice of Allowance dated Oct. 2, 2012 in U.S. Appl. No. 12/853,253.
USPTO; Office Action dated Mar. 12, 2012 in U.S. Appl. No. 12/853,255.
USPTO; Final Office Action dated Jul. 24, 2012 in U.S. Appl. No. 12/853,255.
USPTO; Office Action dated Jan. 18, 2013 in U.S. Appl. No. 12/853,255.
USPTO; Notice of Allowance dated Jun. 20, 2013 in U.S. Appl. No. 12/853,255.
USPTO; Office Action dated Apr. 19, 2012 in U.S. Appl. No. 12/853,268.
USPTO; Final Office Action dated Sep. 17, 2012 in U.S. Appl. No. 12/853,268.
USPTO; Notice of Allowance dated Nov. 21, 2012 in U.S. Appl. No. 12/853,268.
USPTO; Office Action dated May 29, 2012 in U.S. Appl. No. 12/878,984.
USPTO; Office Action dated Oct. 3, 2012 in U.S. Appl. No. 12/878,984.
USPTO; Final Office Action dated Jan. 25, 2013 in U.S. Appl. No. 12/878,984.
USPTO; Notice of Allowance dated Mar. 28, 2013 in U.S. Appl. No. 12/878,984.
USPTO; Office Action dated Sep. 22, 2011 in U.S. Appl. No. 12/880,027.
USPTO; Final Office Action dated Feb. 16, 2012 in U.S. Appl. No. 12/880,027.
USPTO; Office Action dated Dec. 14, 2012 in U.S. Appl. No. 12/880,027.
USPTO; Final Office Action dated Jul. 11, 2013 in U.S. Appl. No. 12/880,027.
USPTO; Office Action dated Jul. 16, 2014 in U.S. Appl. No. 12/880,027.
USPTO; Office Action dated Dec. 18, 2013 in U.S. Appl. No. 12/895,796.
USPTO; Final Office Action dated Jun. 3, 2014 in U.S. Appl. No. 12/895,796.
USPTO; Office Action dated Aug. 25, 2011 in U.S. Appl. No. 13/047,719.
USPTO; Final Office Action dated Dec. 16, 2011 in U.S. Appl. No. 13/047,719.
USPTO; Office Action dated Sep. 11, 2012 in U.S. Appl. No. 13/047,719.
USPTO; Notice of Allowance dated Feb. 28, 2013 in U.S. Appl. No. 13/047,719.
USPTO; Office Action dated Aug. 25, 2011 in U.S. Appl. No. 13/047,747.
USPTO; Final Office Action dated Feb. 7, 2012 in U.S. Appl. No. 13/047,747.
USPTO; Notice of Allowance dated Apr. 18, 2012 in U.S. Appl. No. 13/047,747.
USPTO; Office Action dated Dec. 13, 2012 in U.S. Appl. No. 13/047,747.
USPTO; Notice of Allowance dated Apr. 3, 2013 in U.S. Appl. No. 13/047,747.
USPTO; Office Action dated Apr. 12, 2013 in U.S. Appl. No. 13/106,853.
USPTO; Notice of Allowance dated Aug. 23, 2013 in U.S. Appl. No. 13/106,853.
USPTO; Office Action dated Apr. 18, 2012 in U.S. Appl. No. 13/252,145.
USPTO; Final Office Action dated Sep. 17, 2012 in U.S. Appl. No. 13/252,145.
USPTO; Notice of Allowance dated Nov. 30, 2012 in U.S. Appl. No. 13/252,145.
USPTO; Office Action dated Aug. 1, 2013 in U.S. Appl. No. 12/877,988.
USPTO; Notice of Allowance dated Dec. 24, 2013 in U.S. Appl. No. 12/877,988.
USPTO; Office Action dated Sep. 6, 2013 in U.S. Appl. No. 13/725,383.
USPTO; Office Action dated Oct. 24, 2013 in U.S. Appl. No. 13/725,383.
USPTO; Final Office Action dated Mar. 25, 2014 in U.S. Appl. No. 13/725,383.
USPTO; Office Action dated Sep. 18, 2012 in U.S. Appl. No. 13/752,312.
USPTO; Final Office Action dated Jan. 27, 2014 in U.S. Appl. No. 13/752,312.
USPTO; Final Office Action dated May 23, 2014 in U.S. Appl. No. 13/752,312.
USPTO; Office Action dated Sep. 11, 2013 in U.S. Appl. No. 13/756,468.
USPTO; Notice of Allowance dated Feb. 3, 2014 in U.S. Appl. No. 13/756,468.
USPTO; Office Action dated Aug. 14, 2014 in U.S. Appl. No. 13/791,889.
USPTO; Office Action dated Sep. 10, 2014 in U.S. Appl. No. 13/791,952.
USPTO; Office Ction dated Sep. 15, 2014 in U.S. Appl. No. 13/797,616.
CIPO; Office Action dated Dec. 4, 2001 in Application No. 2,115,929.
CIPO; Office Action dated Apr. 22, 2002 in Application No. 2,115,929.
CIPO; Notice of Allowance dated Jul. 18, 2003 in Application No. 2,115,929.
CIPO; Office Action dated Jun. 30, 2003 in Application No. 2,176,475.
CIPO; Notice of Allowance dated Sep. 15, 2004 in Application No. 2,176,475.
CIPO; Office Action dated May 29, 2000 in Application No. 2,242,174.
CIPO; Office Action dated Feb. 22, 2006 in Application No. 2,244,251.
CIPO; Office Action dated Mar. 27, 2007 in Application No. 2,244,251.
CIPO; Office Action dated Sep. 18, 2002 in Application No. 2,305,865.
CIPO; Notice of Allowance dated May 2, 2003 in Application No. 2,305,865.

(56) **References Cited**

OTHER PUBLICATIONS

EPO; Examination Report dated Oct. 6, 2008 in Application No. 08158682.
EPO; Office Action dated Jan. 26, 2010 in Application No. 08158682.
EPO; Office Action dated Feb. 15, 2011 in Application No. 08158682.
EPO; Search Report dated Nov. 9, 1998 in Application No. 98112356.
EPO; Office Action dated Feb. 6, 2003 in Application No. 99941032.
EPO; Office Action dated Aug. 20, 2004 in Application No. 99941032.
PCT; International Search Report or Declaration dated Nov. 15, 1999 in Application No. PCT/US1999/18178.
PCT; International Search Report or Declaration dated Oct. 9, 1998 in Application No. PCT/US1999/22440.
USPTO; Ex Parte Quayle Office Action dated Dec. 19, 2014 in U.S. Appl. No. 12/880,027.
USPTO; Office Action dated Nov. 17, 2014 in U.S. Appl. No. 12/895,796.
USPTO; Notice of Allowance dated Dec. 17, 2014 in U.S. Appl. No. 13/752,312.
USPTO; Office Action dated Sep. 23, 2014 in U.S. Appl. No. 13/843,947.
USPTO; Office Action dated Nov. 28, 2014 in U.S. Appl. No. 13/843,947.
USPTO; Office Action dated Sep. 22, 2014 in U.S. Appl. No. 13/830,031.
USPTO; Office Action dated Sep. 25, 2014 in U.S. Appl. No. 13/838,601.
USPTO; Final Office Action dated Dec. 5, 2014 in U.S. Appl. No. 13/791,889.
USPTO; Restriction Requirement dated Sep. 17, 2014 in U.S. Appl. No. 13/801,907.
USPTO; Office Action dated Dec. 9, 2014 in U.S. Appl. No. 13/801,907.
USPTO; Restriction Requirement dated Sep. 17, 2014 in U.S. Appl. No. 13/802,203.
USPTO; Office Action dated Dec. 11, 2014 in U.S. Appl. No. 13/802,203.
USPTO; Office Action dated Jan. 9, 2015 in U.S. Appl. No. 13/802,040.
USPTO; Notice of Allowance dated Jan. 30, 2015 in U.S. Appl. No. 13/830,031.
USPTO; Notice of Allowance dated Feb. 4, 2015 in 13/797,616.
USPTO; Final Office Action dated Mar. 3, 2015 in U.S. Appl. No. 13/838,601.
USPTO; Office Action dated Mar. 31, 2015 in U.S. Appl. No. 12/853,238.
USPTO; Notice of Allowance dated Apr. 8, 2015 in U.S. Appl. No. 12/880,027.
USPTO; Office Action dated Apr. 10, 2015 in U.S. Appl. No. 14/027,237.
USPTO; Office Action dated Mar. 3, 2015 in U.S. Appl. No. 13/725,383.
USPTO; Final Office dated Apr. 10, 2015 in U.S. Appl. No. 13/843,947.
USPTO; Notice of Allowance dated Jun. 5, 2015 in U.S. Appl. No. 13/801,907.
USPTO; Restriction Requirement dated Jun. 25, 2015 in U.S. Appl. No. 13/841,938.
USPTO; Final Office Action dated Jul. 8, 2015 in U.S. Appl. No. 13/725,383.
USPTO; Final Office Action dated Jul. 10, 2015 in U.S. Appl. No. 12/853,238.
USPTO; Notice of Allowance dated Jul. 14, 2015 in U.S. Appl. No. 13/802,040.
USPTO; Office Action dated Jul. 24, 2015 in U.S. Appl. No. 13/838,601.
USPTO; Office Action dated Jul. 30, 2015 in U.S. Appl. No. 13/841,594.
USPTO; Final Office Action dated Aug. 20, 2015 in U.S. Appl. No. 14/027,237.
USPTO; Office Action dated Aug. 25, 2015 in U.S. Appl. No. 13/841,938.
USPTO; Final Office Action dated Sep. 11, 2015 in U.S. Appl. No. 13/843,947.
USPTO; Supplemental Notice of Allowance dated Oct. 2, 2015 in U.S. Appl. No. 13/801,907.
USPTO; Ex-Parte Quayle Office Action dated Nov. 4, 2015 in U.S. Appl. No. 14/027,237.
USPTO; Office Action dated Sep. 1, 2015 in U.S. Appl. No. 12/895,796.
USPTO; Ex Parte Quayle Action dated Nov. 4, 2015 in U.S. Appl. No. 14/027,237.
USPTO; Office Action dated Nov. 20, 2015 in U.S. Appl. No. 13/725,383.
USPTO; Office Action dated Dec. 14, 2015 in U.S. Appl. No. 14/687,806.
USPTO; Office Action dated Dec. 15, 2015 in U.S. Appl. No. 13/800,460.
USPTO; Office Action dated Dec. 15, 2015 in U.S. Appl. No. 14/690,064.
USPTO; Office Action dated Dec. 17, 2015 in U.S. Appl. No. 14/286,442.
USPTO; Office Action dated Dec. 18, 2015 in U.S. Appl. No. 14/689,879.
USPTO; Office Action dated Dec. 23, 2015 in U.S. Appl. No. 14/662,100.
USPTO; Office Action dated Dec. 31, 2015 in U.S. Appl. No. 14/690,099.
USPTO; Office Action dated Jan. 4, 2016 in U.S. Appl. No. 14/712,435.
USPTO; Office Action dated Jan. 12, 2016 in U.S. Appl. No. 13/802,203.
USPTO; Notice of Allowance dated Jan. 15, 2016 in U.S. Appl. No. 14/027,237.
USPTO; Office Action dated Jan. 20, 2016 in U.S. Appl. No. 12/853,238.
USPTO; Ex Parte Quayle Action dated Jan. 25, 2016 in U.S. Appl. No. 13/843,947.
USPTO; Office Action dated Feb. 11, 2016 in U.S. Appl. No. 14/690,174.

* cited by examiner

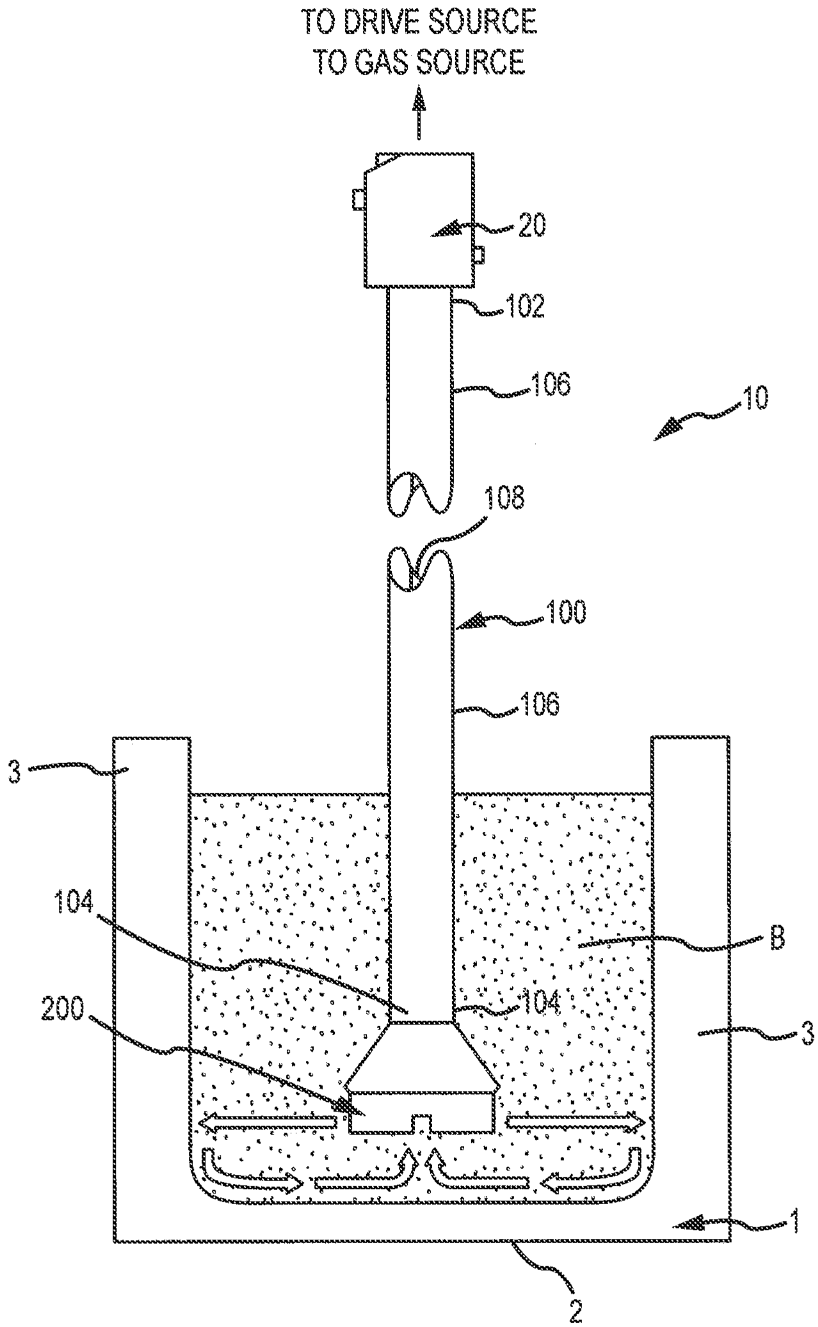

TO DRIVE SOURCE
TO GAS SOURCE
20
102
106
10
108
100
106
3
104
B
104
200
3
1
2

FIGURE 1

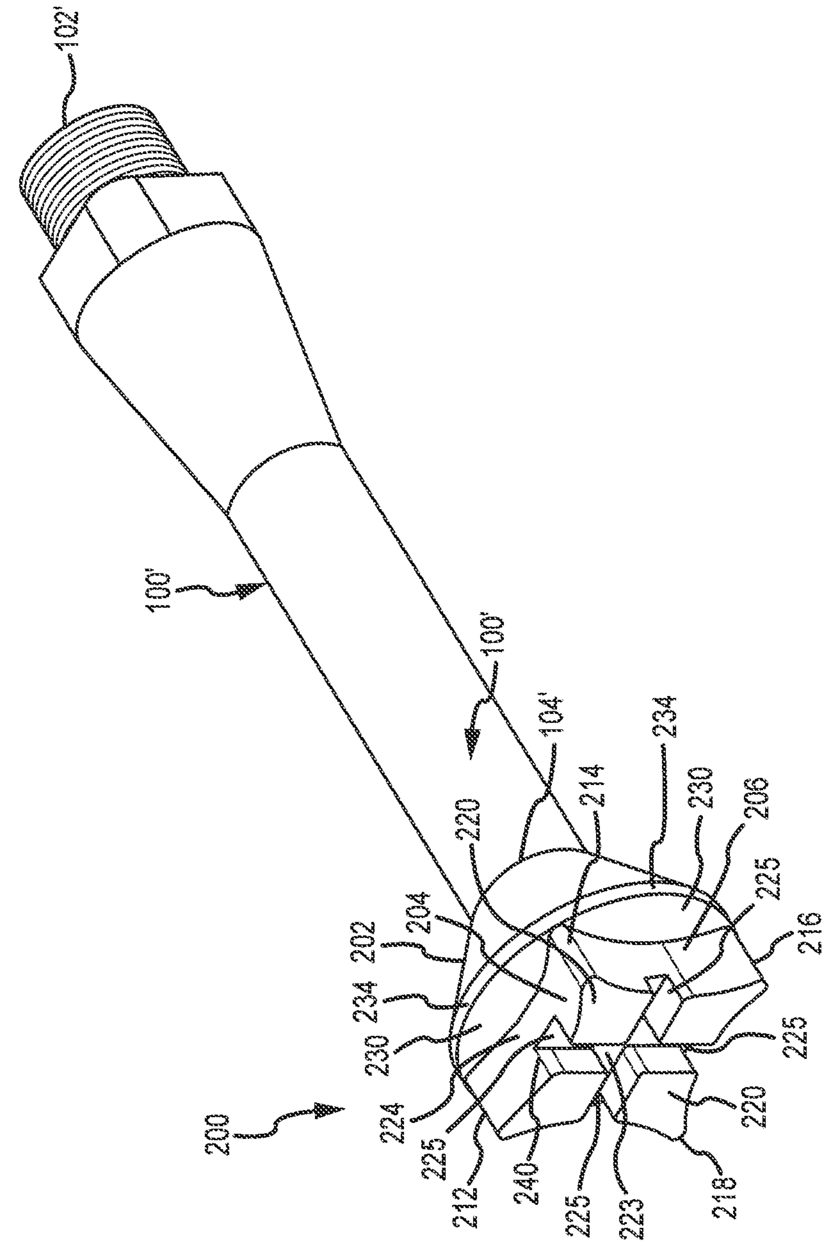

102'
100'
100'
104'
234
220
214
230
206
225
216
204
202
234
230
225
224
225
212
240
225
223
218
220
200

FIGURE 2

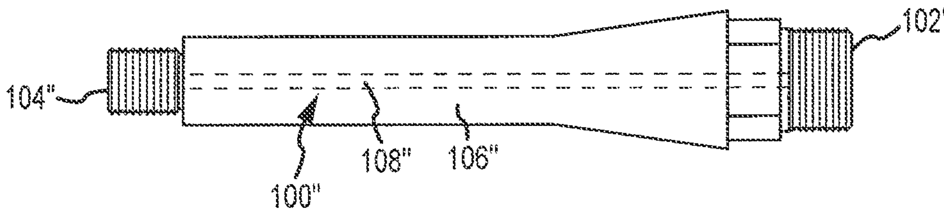


FIGURE 3A

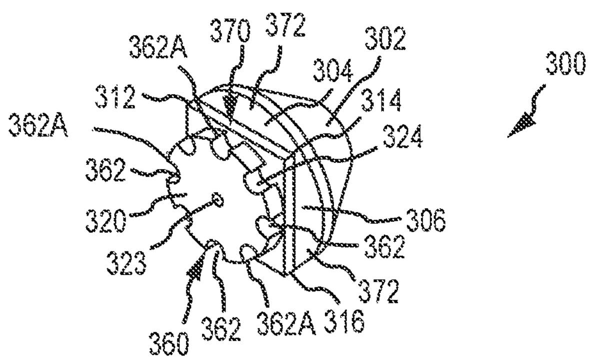


FIGURE 3B

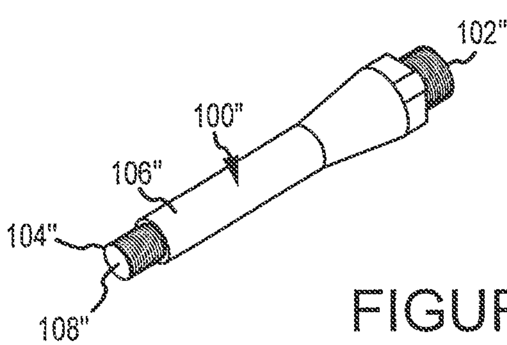


FIGURE 3C

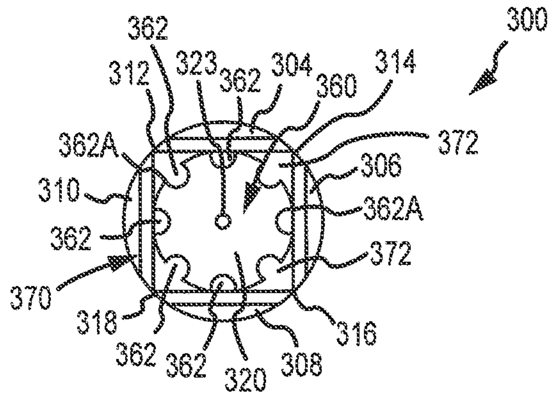


FIGURE 3D

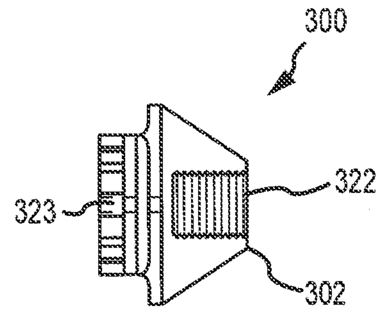


FIGURE 3E

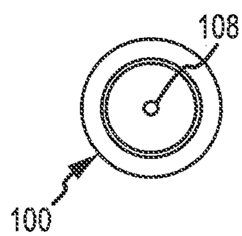
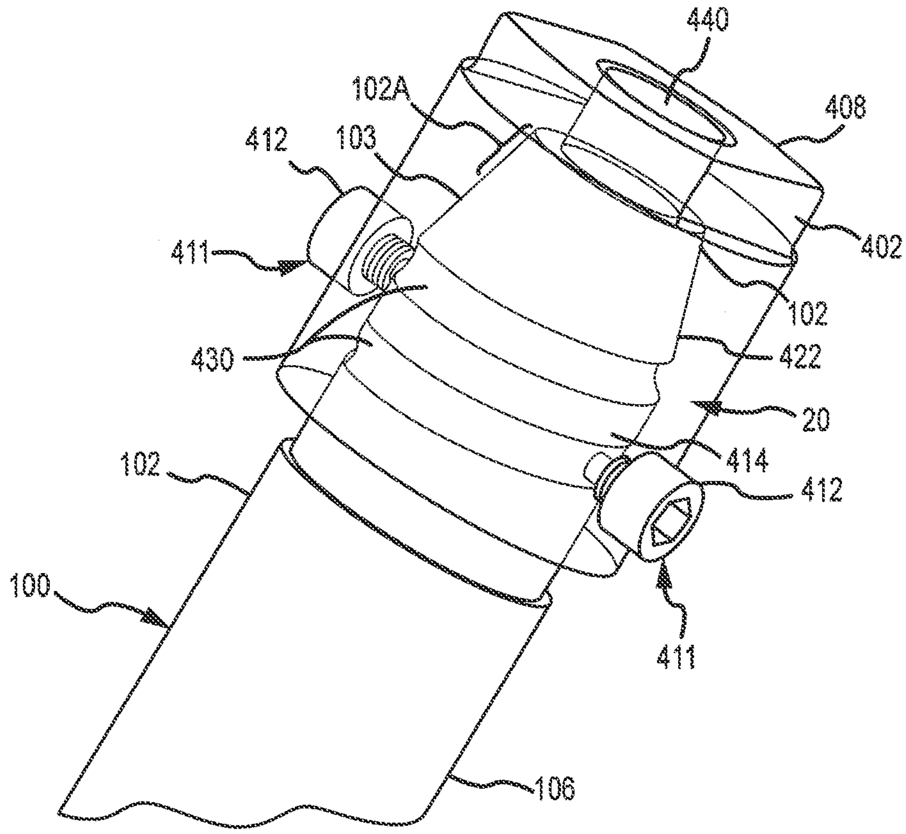


FIGURE 3F



440
408
102A
412
103
402
411
102
430
422
20
414
102
412
100
411
106

FIGURE 4

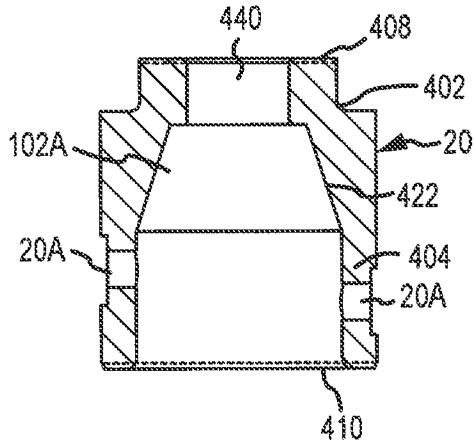


FIGURE 5A

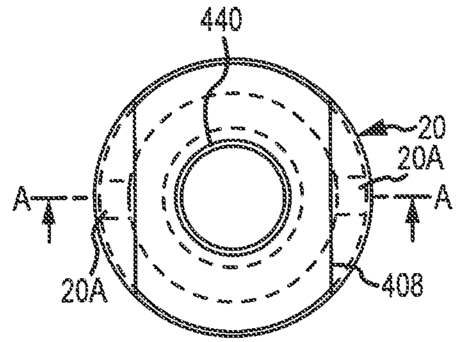


FIGURE 5B

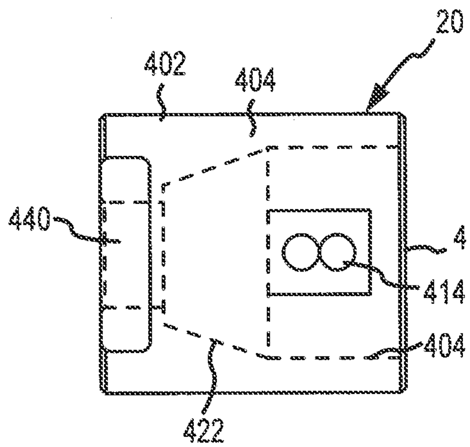


FIGURE 5C

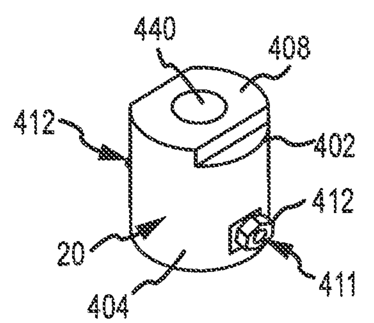


FIGURE 5D

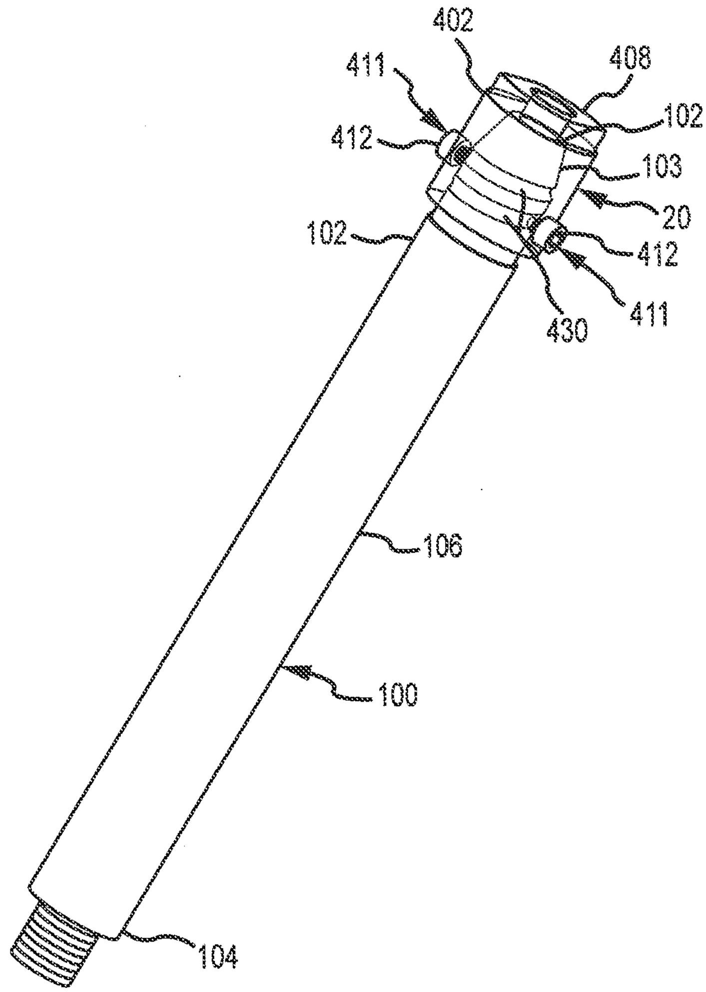


FIGURE 6

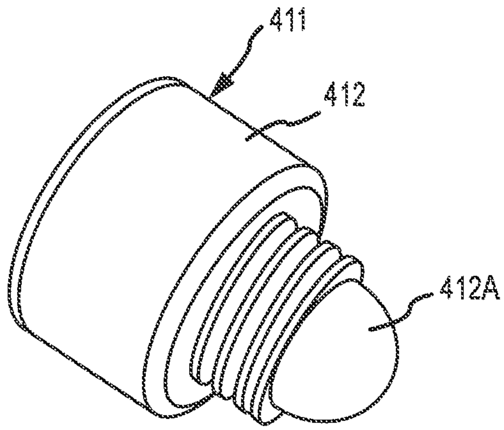


FIGURE 7A

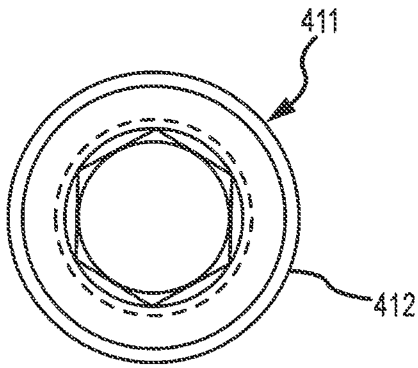


FIGURE 7B

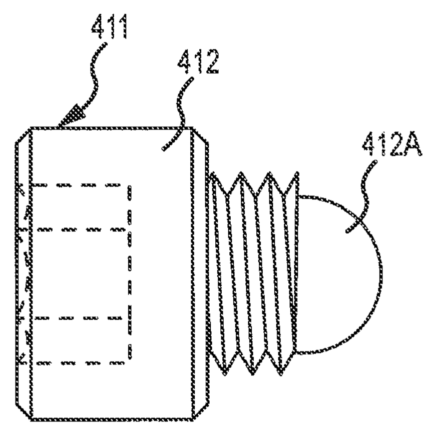


FIGURE 7C

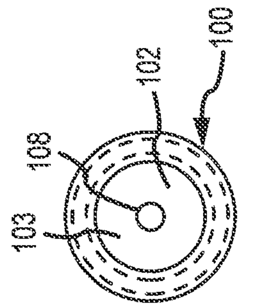


FIGURE 8C

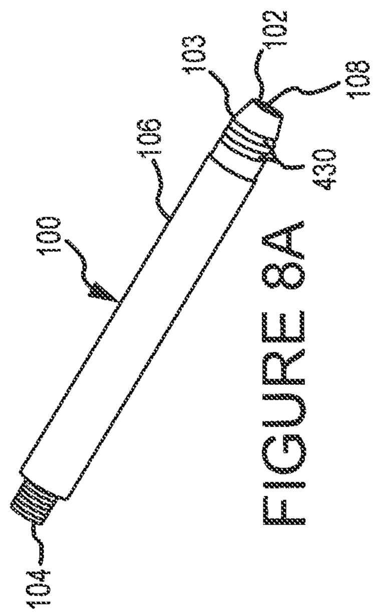


FIGURE 8A

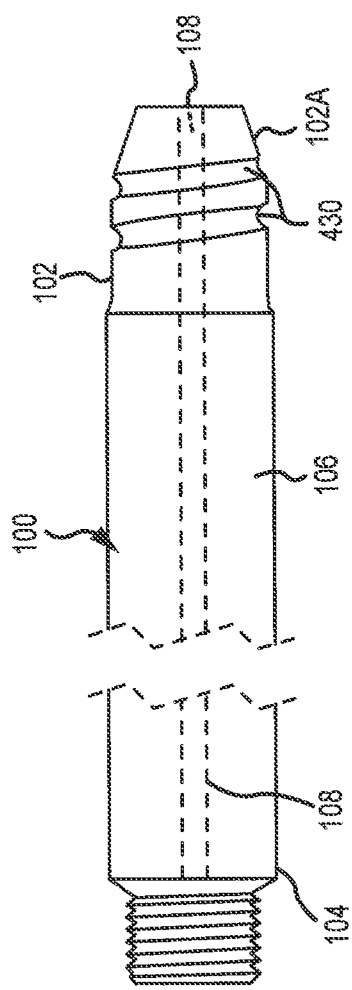


FIGURE 8B

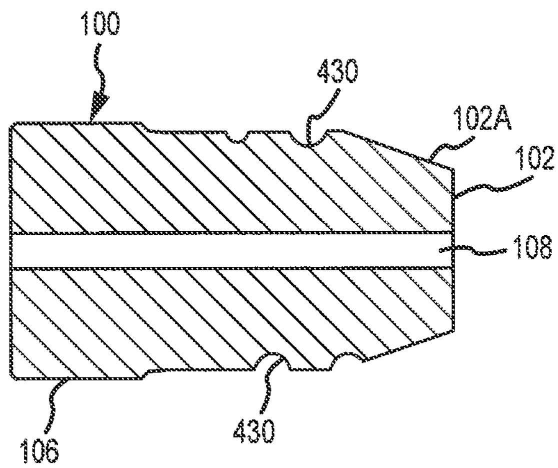


FIGURE 8D

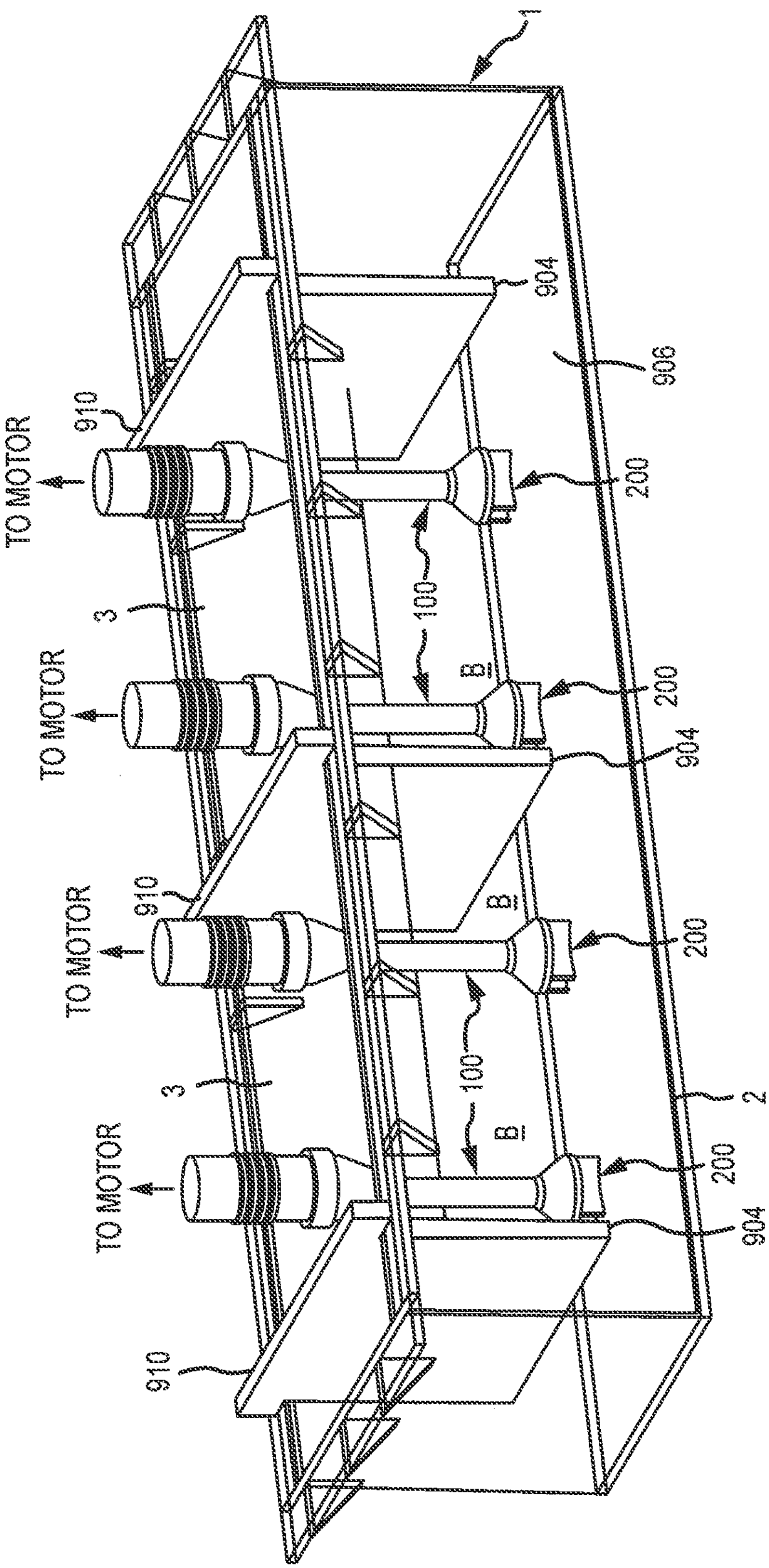

1
904
906
910
TO MOTOR
200
100
3
TO MOTOR
B
200
904
910
TO MOTOR
B
200
100
3
B
TO MOTOR
200
2
904
910

FIG. 9

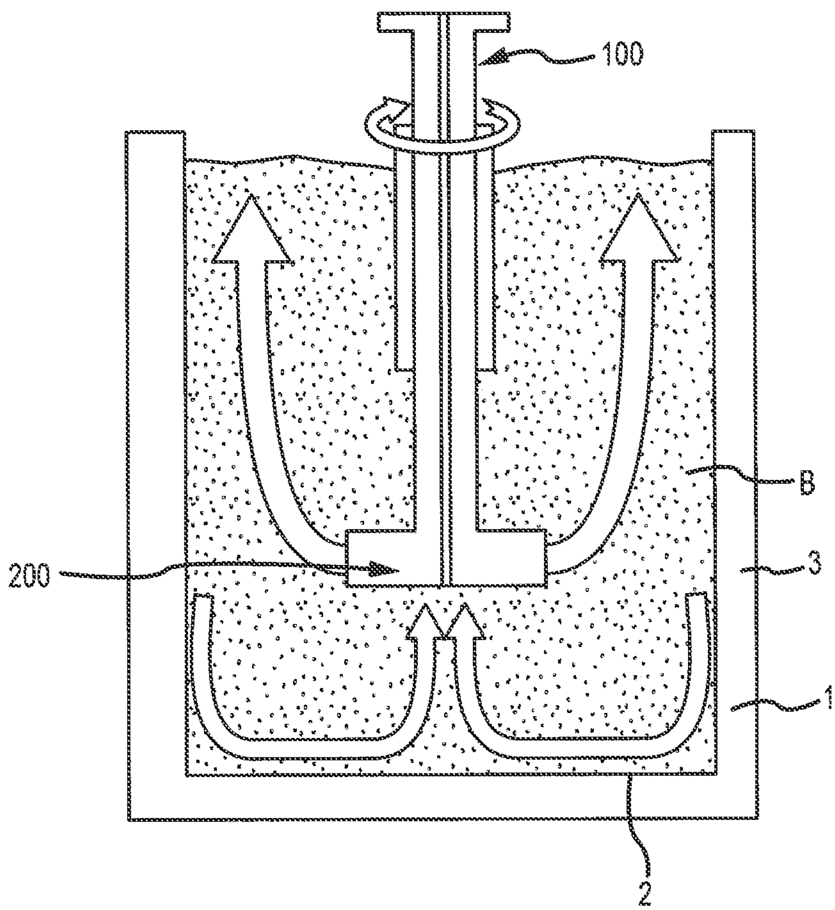


FIGURE 10

ROTARY DEGASSERS AND COMPONENTS THEREFOR

PRIORITY CLAIM

This application claims priority to and is a Divisional Application of U.S. patent application Ser. No. 12/878,984, (now U.S. Pat. No. 8,524,146), filed on Sep. 9, 2010, entitled "Rotary Degassers and Components Therefor," and invented by Paul V. Cooper, which claims priority to U.S. Provisional Application No. 61/240,981, filed on Sep. 9, 2009, entitled "Impeller and Degasser Couplings for Molten Metal Devices," and invented by Paul V. Cooper. The drawings and pages 29-35 of Provisional Application No. 61/240,981 are incorporated herein by reference. U.S. patent application Ser. No. 12/878,984, (now U.S. Pat. No. 8,524,146), is also a continuation in part of and claims priority to U.S. patent application Ser. No. 12/853,255, (now U.S. Pat. No. 8,535,603), entitled "Rotary Degasser and Rotor Therefor," filed on Aug. 9, 2010, and invented by Paul V. Cooper and which claims priority to U.S. Provisional Patent Application No. 61/232,384 entitled "Rotary Degasser and Rotor Therefor," filed on Aug. 7, 2009. The disclosure of U.S. patent application Ser. No. 12/853,255 (now U.S. Pat. No. 8,535,603), is incorporated herein by reference.

FIELD OF THE INVENTION

The invention relates to couplings, impellers and rotary degassers used in molten metal. One aspect of the invention is an impeller shaft for use with an impeller shaft that transfers gas, wherein the coupling decreases the possibility of impeller shaft breakage, gas leakage and maintenance. Another aspect of the invention is an improved impeller for introducing, and mixing gas with molten metal.

BACKGROUND OF THE INVENTION

As used herein, the term "molten metal" means any metal or combination of metals in liquid form, such as aluminum, copper, iron, zinc, and alloys thereof. The term "gas" means any gas or combination of gases, including argon, nitrogen, chlorine, fluorine, Freon, and helium, which may be released into molten metal.

A reverbatory furnace is used to melt metal and retain the molten metal while the metal is in a molten state. The molten metal in the furnace is sometimes called the molten metal bath. Reverbatory furnaces usually include a chamber for retaining a molten metal pump and that chamber is sometimes referred to as the pump well.

Known pumps for pumping molten metal (also called "molten-metal pumps") include a pump base (also called a "base", "housing" or "casing") and a pump chamber (or "chamber" or "molten metal pump chamber"), which is an open area formed within the pump base. Such pumps also include one or more inlets in the pump base, an inlet being an opening to allow molten metal to enter the pump chamber.

A discharge is formed in the pump base and is a channel or conduit that communicates with the molten metal pump chamber, and leads from the pump chamber to the molten metal bath. A tangential discharge is a discharge formed at a tangent to the pump chamber. The discharge may also be axial, in which case the pump is called an axial pump. In an axial pump the pump chamber and discharge may be the essentially the same structure (or different areas of the same

structure) since the molten metal entering the chamber is expelled directly through (usually directly above or below) the chamber.

A rotor, also called an impeller, is mounted in the pump chamber and is connected to a drive shaft. The drive shaft is typically a motor shaft coupled to a rotor shaft, wherein the motor shaft has two ends, one end being connected to a motor and the other end being coupled to the rotor shaft. The rotor shaft also has two ends, wherein one end is coupled to the motor shaft and the other end is connected to the rotor. Often, the rotor shaft is comprised of graphite, the motor shaft is comprised of steel, and the two are coupled by a coupling, which is usually comprised of steel.

As the motor turns the drive shaft, the drive shaft turns the rotor and the rotor pushes molten metal out of the pump chamber, through the discharge, which may be an axial or tangential discharge, and into the molten metal bath. Most molten metal pumps are gravity fed, wherein gravity forces molten metal through the inlet and into the pump chamber as the rotor pushes molten metal out of the pump chamber.

Molten metal pump casings and rotors usually, but not necessarily, employ a bearing system comprising ceramic rings wherein there are one or more rings on the rotor that align with rings in the pump chamber such as rings at the inlet (which is usually the opening in the housing at the top of the pump chamber and/or bottom of the pump chamber) when the rotor is placed in the pump chamber. The purpose of the bearing system is to reduce damage to the soft, graphite components, particularly the rotor and pump chamber wall, during pump operation. A known bearing system is described in U.S. Pat. No. 5,203,681 to Cooper, the disclosure of which is incorporated herein by reference. U.S. Pat. Nos. 5,951,243 and 6,093,000, each to Cooper, the disclosures of which are incorporated herein by reference, disclose, respectively, bearings that may be used with molten metal pumps and rigid coupling designs and a monolithic rotor. U.S. Pat. No. 2,948,524 to Sweeney et al., U.S. Pat. No. 4,169,584 to Mangalick, and U.S. Pat. No. 6,123,523 to Cooper (the disclosure of the aforementioned patent to Cooper is incorporated herein by reference) also disclose molten metal pump designs. U.S. Pat. No. 6,303,074 to Cooper, which is incorporated herein by reference, discloses a dual-flow rotor, wherein the rotor has at least one surface that pushes molten metal into the pump chamber.

The materials forming the molten metal pump components that contact the molten metal bath should remain relatively stable in the bath. Structural refractory materials, such as graphite or ceramics, that are resistant to disintegration by corrosive attack from the molten metal may be used. As used herein "ceramics" or "ceramic" refers to any oxidized metal (including silicon) or carbon-based material, excluding graphite, capable of being used in the environment of a molten metal bath. "Graphite" means any type of graphite, whether or not chemically treated. Graphite is particularly suitable for being formed into pump components because it is (a) soft and relatively easy to machine, (b) not as brittle as ceramics and less prone to breakage, and (c) less expensive than ceramics.

Three basic types of pumps for pumping molten metal, such as molten aluminum, are utilized: circulation pumps, transfer pumps and gas-release pumps. Circulation pumps are used to circulate the molten metal within a bath, thereby generally equalizing the temperature of the molten metal. Most often, circulation pumps are used in a reverbatory furnace having an external well. The well is usually an extension of a charging well where scrap metal is charged (i.e., added).

Transfer pumps are generally used to transfer molten metal from the external well of a reverbatory furnace to a different location such as a launder, ladle, or another furnace. Examples of transfer pumps are disclosed in U.S. Pat. No. 6,345,964 B1 to Cooper, the disclosure of which is incorporated herein by reference, and U.S. Pat. No. 5,203,681.

Gas-release pumps, such as gas-injection pumps, circulate molten metal while releasing a gas into the molten metal. In the purification of molten metals, particularly aluminum, it is frequently desired to remove dissolved gases such as hydrogen, or dissolved metals, such as magnesium, from the molten metal. As is known by those skilled in the art, the removing of dissolved gas is known as "degassing" while the removal of magnesium is known as "demagging." Gas-release pumps may be used for either of these purposes or for any other application for which it is desirable to introduce gas into molten metal. Gas-release pumps generally include a gas-transfer conduit having a first end that is connected to a gas source and a second submerged in the molten metal bath. Gas is introduced into the first end of the gas-transfer conduit and is released from the second end into the molten metal. The gas may be released downstream of the pump chamber into either the pump discharge or a metal-transfer conduit extending from the discharge, or into a stream of molten metal exiting either the discharge or the metal-transfer conduit. Alternatively, gas may be released into the pump chamber or upstream of the pump chamber at a position where it enters the pump chamber. A system for releasing gas into a pump chamber is disclosed in U.S. Pat. No. 6,123,523 to Cooper. Furthermore, gas may be released into a stream of molten metal passing through a discharge or metal-transfer conduit wherein the position of a gas-release opening in the metal-transfer conduit enables pressure from the molten metal stream to assist in drawing gas into the molten metal stream. Such a structure and method is disclosed in U.S. application Ser. No. 10/773,101 entitled "System for Releasing Gas into Molten Metal", invented by Paul V. Cooper, and filed on Feb. 4, 2004, the disclosure of which is incorporated herein by reference.

Generally, a degasser (also called a rotary degasser) is used to remove gaseous impurities from molten metal. A degasser typically includes (1) an impeller shaft having a first end, a second end and a passage (or conduit) therethrough for transferring gas, (2) an impeller (also called a rotor), and (3) a drive source (which is typically a motor, such as a pneumatic motor) for rotating the impeller shaft and the impeller. The degasser impeller shaft is normally part of a drive shaft that includes the impeller shaft, a motor shaft and a coupling that couples the two shafts together. Gas is introduced into the motor shaft through a rotary union. Thus, the first end of the impeller shaft is connected to the drive source and to a gas source (preferably indirectly via the coupling and motor shaft). The second end of the impeller shaft is connected to the impeller, usually by a threaded connection. The gas is released from the end of the impeller shaft submersed in the molten metal bath, where it escapes under the impeller. Examples of rotary degassers are disclosed in U.S. Pat. No. 4,898,367 entitled "Dispersing Gas Into Molten Metal," U.S. Pat. No. 5,678,807 entitled "Rotary Degassers," and U.S. Pat. No. 6,689,310 to Cooper entitled "Molten Metal Degassing Device and Impellers Therefore," the respective disclosures of which are incorporated herein by reference.

Known coupling-to-impeller shaft connections are usually threaded, and gas can seep past the threaded connections, especially after the threads have been worn after operation of the degasser, causing the graphite threads of the impeller shaft to wear. The leaks waste gas, and if caustic gas such as chlorine is used, the gas can interact with nearby steel causing the steel to oxidize as well as releasing the caustic chlorine gas into the atmosphere creating an environmental hazard.

Another problem with conventional devices is that broken or worn impeller shafts are difficult to remove. The impeller shafts, also called "shafts," "degasser shafts," or "degasser impeller shafts," herein, are usually formed of graphite, silicon carbide or some combination thereof. The impeller shafts are typically connected to a coupling by a threaded connection wherein an internal cavity of a collar of the coupling is threaded and the external surface of the impeller shaft is threaded, and threadingly received in the internal cavity of the coupling. Stress is placed on the impeller shaft as it rotates and the shaft is weakened by the threads, so the impeller shaft tends to eventually break, and it typically breaks just below the coupling and the end still threaded into the coupling must be chiseled out, which is time consuming.

Another known way to couple an impeller shaft to a steel motor drive shaft is by threadingly connecting it to a threaded projection extending from the drive shaft. The projection comprises a threaded outer surface that is received in a threaded bore of the graphite impeller shaft. In this case, the single connection serves to both transfer torque to the impeller shaft and to create a gas-tight seal with a threaded bore in the impeller shaft. The impeller shaft is hollow, having an internal bore through which gas is transferred ultimately into the molten metal bath. Although this design allows for relatively easy removal of the impeller shaft if the shaft breaks, the impeller shaft is not supported or aligned by a coupling and the impeller shaft tends to wobble and the graphite threads in the bore wear quickly. As the fit loosens, the impeller shaft becomes more eccentric in its movement, i.e., it wobbles more, and eventually breaks.

One attempt to solve the problems associated with coupling a graphite shaft to a steel drive shaft is shown in U.S. Pat. No. 5,203,681 to Cooper entitled "Submersible Molten Metal Pump." This reference discloses a two-piece clamp held in position by a through bolt. Shafts retained by this clamp must include a cross axial bore to allow the bolt to pass through the shaft. This structure would not be used by one skilled in the art to couple a hollow shaft that functions as a gas-transfer conduit because gas could leak from the holes formed as part of the cross axial bore.

Further, many conventional devices do not adequately mix the gas being introduced into the molten metal. The gas can become trapped in a pocket within the impeller or rotor, or is otherwise not properly dispersed into the molten metal. Additionally, if rotated too fast in order to more thoroughly mix the gas and molten metal, "cavitation" can occur. Cavitation is when essentially a whirlpool is created that pulls air from the surface into the molten metal. This causes oxidation at the surface of the bath and slag or other impurities may be formed.

SUMMARY OF THE INVENTION

In accordance with the invention a rotary degasser for introducing gas into molten metal is disclosed. In one embodiment the degasser comprises: (1) an impeller (or degasser) shaft including a first end for connecting to a coupling without the use of threads and an internal passage that transfers gas; (2) an impeller coupled to a second end of the impeller shaft, wherein the impeller comprises: at least one impeller opening communicating with the impeller shaft passage, and the opening allows gas to escape into the molten metal under the impeller and enter at least one channel in the bottom of the impeller where it is directed to at least one cavity, which is preferably defined in part by a curved side of the impeller; and (3) a coupling having a collar that receives the first end of the impeller shaft and retains it without a threaded connection. The impeller shaft is preferably connected to a drive source by the coupling and the drive source turns the impeller shaft and the impeller. The impeller thereby displaces the molten metal while simultaneously gas is introduced into the molten metal through the opening.

An impeller of the invention may include at least a top surface and one cavity defined by a curved impeller side surface (or portion) juxtaposed an edge or other shearing structure. In the preferred embodiment, the distance from the center of each curved impeller side surface is closer to a center of the impeller than the distance from each of the shearing structures to the center of the impeller. One or more channels may be formed in the bottom surface of the impeller, wherein each channel extends from the opening in the bottom of the impeller to the center of a respective cavity. There may be four channels, wherein each extends to the center of a respective cavity. The impeller is preferably threadingly received onto the second end of the impeller shaft.

In one embodiment a coupling configured to be connectable to an impeller shaft preferably comprises an inner surface defining a smooth tapered, wall, and (2) at least one opening to receive a retention device, such as a set screw. An impeller shaft according to the invention is preferably not threadingly coupled to the coupling, so the coupling need not include threads.

Another impeller according to the invention has at least one cavity in a first vertical position and at least one cavity in a second vertical position, wherein the second vertical position is above the first vertical position. Preferably, there is a plurality of cavities in each of the two vertical positions. Each cavity is juxtaposed an edge, or other shearing structure. The impeller includes a gas release opening for allowing gas to escape under the impeller. At least some of the gas then enters the first and/or second cavity(ies), where it is mixed with molten metal as the rotor rotates. This impeller thus has two stages at which gas can be mixed with the molten metal.

Both the forgoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention as claimed. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description serve to explain the principals of the invention and not to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of one embodiment of a rotary degasser according to the invention.

FIG. **2** is a perspective view of an impeller and impeller shaft according to one embodiment of the present invention.

FIGS. **3**A-**3**F are views of an alternate embodiment of an impeller and impeller shaft according to the invention.

FIG. **4** depicts one embodiment of a coupling/impeller shaft connection according to the invention.

FIGS. **5**A-**5**D depicts alternative views of the coupling shown in FIG. **4**.

FIG. **6** depicts an embodiment of the coupling/impeller shaft connection as shown in FIG. **4**, but showing the entire impeller shaft.

FIGS. **7**A-**7**C depicts an embodiment of a set screw according to the invention.

FIGS. **8**A-**8**D depict an impeller shaft according to one embodiment of the invention.

FIG. **9** depicts a plurality of rotary degassers according to the invention separated by dividers in a molten metal bath.

FIG. **10** depicts the flow of molten metal and gas mixture utilizing a rotary degasser according to the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference will now be made in detail to the present exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. FIG. **1** depicts a gas-release device **10** according to the invention. Device **10** is adapted to operate in a molten metal bath B contained within a vessel **1**. Vessel **1** includes a bottom **2** and side walls **3**. Vessel **1** may have any suitable size, shape, and configuration.

The exemplary rotary degasser **10** includes an impeller shaft **100** (also shown are shafts **100'** and **100"**), an impeller **200** and a coupling **20** for coupling the impeller shaft to the motor shaft of a drive source (not shown). Impeller shaft **100**, impeller **200**, and each of the impellers used in the practice of the invention, are preferably made of graphite impregnated with oxidation-resistant solution, although any material capable of being used in a molten metal bath, such as ceramic, or non-impregnated graphite could be used. Oxidation and erosion treatments for graphite parts are practiced commercially, and graphite so treated can be obtained from sources known to those skilled in the art.

The drive source can be any structure, system, or device capable of rotating shaft **100** and impeller **200** and is preferably a pneumatic motor or electric motor, the respective structures of which are known to those skilled in the art. The drive source can be connected to impeller shaft **100** in any suitable manner, but is preferably indirectly connected by a motor shaft that is connected to one end of coupling **20**, whereas the other end (or collar) of coupling **20** is connected to a first end **102** of the impeller shaft **100**. The motor shaft is preferably comprised of steel, comprises an inner passage for the transfer of gas, and is preferably in communication with a rotary union, which releases gas from a gas source into the motor shaft, as is known by those skilled in the art. A typical rotary union is a rotary union of the type described in U.S. Pat. No. 6,123,523 to Cooper, filed Sep. 11, 1998, the disclosure of which from page 9, line 21 to page 10, line 23, and FIGS. 4 and 4D, are incorporated herein by reference.

As is illustrated in FIGS. **1**, **4** and **6**, shaft **100** comprises a first end **102**, a second end **104**, a sidewall **106** and an inner passage **108** for transferring gas. Shaft **100** may be a unitary structure or may be a plurality of pieces connected together. The purpose of shaft **100** is to connect to an impeller to (1) rotate the impeller, and (2) transfer gas to the bottom surface of the impeller. Any structure capable of performing these functions can be used in conjunction with the present invention.

A preferred embodiment of the shaft **100** at end **102** is shown in FIGS. **4** and **6**. In this embodiment, first end **102** (which is received in coupling **20**) is tapered. It also comprises at least one groove **430** for receiving at least one retainer **411**. In this exemplary embodiment, the groove **430** in shaft **100** is helical and extends along the shaft **100** such that preferably two or more retainers **411** (and preferably as many as four although any number may be used) can engage the groove at different positions to retain impeller shaft **100**. As used herein with respect to end **102** of impeller **100**, "groove" means any recess, indentation or structure designed to receive a retainer.

The tapered portion **102**A of end **102** of the impeller shaft **100** aligns with an internal, tapered portion **422** of coupling

200, as seen in FIGS. **4**, **5**A and **5**C. This alignment helps prevent gas from escaping between the tapered portion **102**A of the impeller shaft **100** and the interior, tapered portion of the coupling **422**. The groove **430** could extend onto the tapered portion **102**A of the shaft **100**, but it is preferred that the groove does not extend onto portion **102**A, since it may then weaken end **102**. The impeller shaft **100** is preferably threaded at second end **104** for being threadingly connected to impeller **200**, although second end **104** may be configured to couple with the impeller **200** in any suitable manner.

An embodiment of a coupling according to the present invention is shown in FIGS. **4**-**6**. Coupling **20** vertically and rigidly couples a motor shaft to an impeller shaft, such as impeller shaft **100**. Referring to FIG. **5**, coupling **20** is preferably a one-piece coupling incorporating two coupling members, first member **402** and second member **404**. Member **402** can be any structure designed to connect to and receive suitable driving force from a motor shaft. In the preferred embodiment, coupling **402** is designed to receive a motor shaft (which is preferably cylindrical and/or keyed), within the opening **440** formed in the member **402**. The motor shaft may be retained within the opening **440** in any suitable manner, such as by using set screws **412** positioned in apertures **20**A of the coupling **20** (not shown) spaced about the circumference of member **402**. In such a configuration, the set screws can be tightened against motor shaft to help retain shaft within the opening **440**.

Second coupling member **404** (best seen in FIGS. **5**A-**5**C) is configured to receive the impeller shaft **100** through opening **410**. The coupling member **404** may engage the impeller shaft **100** in any suitable manner. In the present exemplary embodiment, one or more retainers **411** (which may include bosses, bolt-retention devices, cap screws or set screws **412**) engage the shaft **100** through apertures **20**A.

In one embodiment, referring now to FIGS. **7**A-**7**C, each of two retention devices **411** comprises a set screw **412** that aligns with an aperture **20**A formed in coupling member **404**. Each set screw **412** is tightened to engage the shaft **100**, preferably by using a tool, such as an Allen wrench, in order to secure shaft **100** in second coupling member **404**. The threaded portion of each screw **412** preferably interfaces with corresponding threads around the aperture **414**. The portion of each screw **412** that engages the impeller shaft **100** may be any size, shape, and configuration to retain the impeller shaft **100** within the coupling **20**. In the exemplary embodiment depicted in FIGS. **7**A-**7**C, the end of each set screw **412** is sized, shaped, and configured to engage a groove **430** formed in the surface of the impeller shaft **100**.

When end **102** (as shown in FIGS. **8**A-**8**D) is received in bore **404**, tapered portion **103** of the impeller shaft **100** is received into the tapered portion **422**. When these tapered, generally smooth surfaces align, the close fit helps to prevent gas leakage and helps to center the shaft **100** and reduce shaft vibration.

Turning now to FIGS. **2** and **3**A-**3**E, embodiments of impeller **200** are shown. Impeller **200** is designed to displace a relatively large quantity of molten metal and thoroughly mix the gas being released into the molten metal. Therefore, impeller **200** can, at a slower speed (i.e., lower revolutions per minute (rpm)), mix the same amount of gas with molten metal as conventional devices operating at higher speeds. Impeller **200** can preferably also operate at a higher speed at which it would mix more gas and molten metal than conventional devices operating at the same higher speed.

By operating impeller **200** at a lower speed less stress is transmitted to the moving components, which leads to longer component life, less maintenance and less downtime. Another advantage that may be realized by operating the impeller at slower speeds is the elimination of a vortex. Some known devices must be operated at high speeds to achieve a desired efficiency. This can create a vortex that draws air into the molten metal from the surface of bath B. The air can lead to metal ingots and finished parts that have air pockets, which is undesirable and/or to the formation of dross. As shown by the arrows in FIG. **10**, for example, the impeller **200** of the present invention circulates gas throughout the molten metal bath B as it rotates without creating a vortex.

In one embodiment, impeller **200** comprises a top surface **202**, sides **204**, **206**, **208** (not shown) and **210** (not shown) corners **212**, **214**, **216** and **218**, and a lower surface **220**. Impeller **200** is preferably imperforate, rectangular and most preferably square in plan view, with sides **204**, **206**, **208** and **210** being preferably equal in length. It also is possible that impeller **200** could be triangular, pentagonal, or otherwise polygonal in plan view. A connector (not shown) is formed in top surface **202**. The connector is preferably a threaded bore that extends from top surface **202** to lower surface **220** and terminates in gas-release opening **223**, though the impeller **200** can be connected to the shaft **100** in any suitable manner.

This exemplary impeller **200** includes one or more cavities **224** defined in part by each of curved sides **204**, **206**, **208** and **210**, which are beneath upper surface **230**. Each cavity **224** is preferably symmetrical about the center of its respective side (**204**, **206**, **208**, or **210**), although one or more of the cavities could be formed off center from its respective side. The cavities need not be identical to each other as long as gas escaping through the gas-release opening enters each cavity where it is ultimately mixed with the molten metal entering the cavity. The invention could function with fewer than or more than four cavities **224**. Additionally, the cavities may be formed in any portion of impeller **200**, rather than being formed at 90-degree intervals by the sides (**204**, **206**, **208**, or **210**) as shown in FIG. **2**. Additionally, a cavity may have any suitable size, shape, and configuration.

In the present exemplary embodiment, each cavity preferably comprises an identical structure, therefore only one cavity **224** shall be described. Cavity **224** is partially defined by concave side surface **204**, wherein the distance from the center of the curved surface **204** is closer to a center of the impeller **200** than the distance from ends (**212**, **214**) of the curved surface **204** to the center of the impeller **200**. Cavity **224** is further defined by upper surface **230**. In the present exemplary embodiment, surface **230** of the impeller **200** is substantially flat and circular as viewed from the bottom of the impeller **200**.

The impeller **200** may comprise one or more channels **225** in the bottom surface **220** of the impeller **200**. The channels **225** may be any size, shape, and configuration. In the present exemplary embodiment, the device comprises four channels **225**, one that extends to in each of the four side cavities.

The edges, such as edges **212**, **214**, **216** and **218**, act as sheering surfaces to break apart gas bubbles into smaller bubbles as the rotor **200** rotates. The impeller **200** is threadingly received onto the impeller shaft. A lip **234** is formed between top wall **230** and top surface **202**; lip **234** preferably comprises a minimum width of one quarter of an inch. Lower surface **220** comprises edges **240** juxtaposed each of the recesses **224**. The impeller **200** is comprised of a heat resistant material such as graphite or ceramic.

In one embodiment, the second end **104** of shaft **100** is preferably connected to impeller **200** by threading end **104** into a connector (not shown) on the impeller. If desired, shaft **100** could be connected to impeller **200** by techniques other than a threaded connection, such as by being cemented, pinned or in any other suitable manner. The use of coarse threads (4 pitch, UNC) facilitates manufacture and assembly. The threads may be tapered.

Upon placing impeller **200** in molten metal bath B and releasing gas through passage **108**, the gas will be released through gas-release opening **223** and at least some will flow outwardly through the channels **225** in lower surface **220**, and into each cavity.

As impeller **200** turns, the gas in each of cavities **224** mixes with the molten metal entering the cavity and this mixture is pushed outward from impeller **200**. The released gas will also be sheared into smaller bubbles as they are struck by a shearing surface when rotor **200** rotates.

By using impeller **200**, high volumes of gas can be mixed with the molten metal at relatively low impeller speeds. Unlike some conventional devices that do not have cavities, the gas cannot simply rise past the side of the impeller **200**. Instead at least some of the gas enters the cavities **224** and is mixed with the molten metal.

An alternate, impeller **300** is shown in FIGS. **3**A-**3**F. Impeller **300** is preferably imperforate, formed from graphite and connected to, and driven by, a shaft such as shaft **100** or shaft **100**". Impeller **300** further includes a connective portion **304**, which is preferably a threaded bore, but can be any structure capable of drivingly engaging shaft **100**.

Impeller **300** includes two sets of cavities, wherein each set is at a different vertical position, that can capture gas and mix it with molten metal. Thus, impeller **300** is a two-stage impeller with respect to mixing gas and molten metal. Impeller **300** comprises a top surface **302**, a bottom surface **320**, a first stage **360** and a second stage **370**. First stage **360** includes a plurality of cavities **362** wherein each cavity is juxtaposed by at least one edge, or other shearing structure, **362**A.

Impeller **300** also has a second stage **370** that includes four sides **304**, **306**, **308** and **310** four corners **312**, **314**, **316** and **318**, and cavities **372**. Impeller **300** is preferably imperforate, and rectangular (and most preferably square in plan view, with sides **304**, **306**, **308** and **310** being preferably equal in length). It also is possible that impeller **300** could be triangular, pentagonal, or otherwise polygonal in plan view. A connector **322** is formed in top surface **302**. The connector is preferably a threaded bore that extends from top surface **302** to lower surface **320** and terminates in gas-release opening **323**, though any other suitable connector may be used.

One or more cavities **372** are formed in part by sides **304**, **306**, **308** and **310**. Each cavity **372** is preferably symmetric about the center of its respective side, although one or more of the cavities could be formed off center. Further, the invention could function with fewer than or more than the cavities shown. Additionally, the cavities may be formed in any suitable portion of impeller **300** and may be of any suitable size, shape, or configuration.

An impeller **300** rotates, gas is released through opening **323** and at least some of the gas enters the one or more cavities **362** and the one or more cavities **372**. The respective edges, or other shearing structures **362**A and **372**A break the gas into smaller bubbles as rotor **300** rotates thereby helping to disperse the gas into the molten metal.

Referring now to FIG. **9**, any number of molten metal degassers of the present invention, as described above, may be employed in a molten metal bath B. In this exemplary embodiment, a plurality of degassers are disposed in a molten metal bath B separated by dividers **910**. The dividers **910** may be made out of any suitable heat resistant material. In the preferred embodiment they are made from the same material as the walls of the molten metal bath B. The dividers **910** may be any suitable size, shape, and configuration and may partially or completely separate portions of the vessel **1**. In one embodiment, the dividers **910** couple to the top surface of the molten metal bath B; however, the dividers **910** may couple to any wall of the vessel **1** such as a side wall **3**, bottom surface **2**, or be suspended by an alternative support structure. The dividers **910** may be coupled to the vessel **1** in any suitable manner, such as by pressure fitting, cementing, clamping, welding, and/or being formed as part of the vessel. The dividers **910** are may be positioned in various locations within the vessel **1** or bath B. In some embodiments the placement of the dividers **910** may travel the entire length of the vessel **1** (they may be placed in any position) and may be repositioned into a different location with ease. The dividers **910** may divide each degasser, two degassers or more than two degassers. Any suitable number of dividers **910** may be implemented. Multiple dividers **910** may be made of different materials, different dimensions and sizes, and may comprise different openings for molten metal to pass through.

As shown in FIG. **9**, there is preferably no gap between the sides of the divider **910** and the side walls **3** of vessel **1**, as the divider **910** runs the entire width of the molten metal bath. In this embodiment, there is a gap between the bottom surface **906** of the molten metal bath B to the bottom most edge **904** of divider **910** to allow molten metal to flow between the chambers.

Having thus described some embodiments of the invention, other variations and embodiments that do not depart from the spirit of the invention will become apparent to those skilled in the art. The scope of the present invention is thus not limited to any particular embodiment, but is instead set forth in the appended claims and the legal equivalents thereof. Unless expressly stated in the written description or claims, the steps of any method recited in the claims may be performed in any order capable of yielding the desired result.

What is claimed is:

1. An impeller having a top surface and a bottom surface, the impeller for dispersing gas into molten metal and comprising:

a continuous, axially aligned passage through the impeller, and through which gas can be transferred from the top surface to the bottom surface;

the passage terminating at an opening in the bottom surface through which gas can be released; and

at least one open channel on the bottom surface of the impeller in communication with the opening in the bottom surface of the impeller, the at least one open channel for directing the gas; and at least one cavity comprising a top surface and at least one curved side surface defined by a radius and terminating at an edge, and the at least one channel extending from the center of the impeller through the center of the at least one curved side surface of the cavity to direct gas therein;

wherein the edge is a shearing structure that shears gas existing the at least one cavity.

2. The impeller of claim **1** further comprising a plurality of cavities and a plurality of channels, wherein each of the plurality of channels leads to one of the plurality of cavities.

3. The impeller of claim **1** wherein each of the at least one open channels extends from the center of the impeller through the center of one of the at least one curved side surfaces.

4. The impeller of claim **1** that is comprised of graphite.

5. The impeller of claim **1**, wherein the top surface has an outer perimeter and each of the at least one curved side surfaces is beneath and inside the outer perimeter of the top surface.

6. The impeller of claim **1** that has four channels and each channel leads through the center of a respective one of at least one of the curved side surfaces.

7. An impeller for use in a rotary degasser, the impeller comprising:

a bottom opening in the bottom of the impeller through which gas can escape; and

a plurality of first cavities for capturing at least some of the gas released from the bottom opening, wherein each of the plurality of first cavities has a top surface, a concave curved side surface and a cavity opening and an outer edge juxtaposed the cavity opening, wherein at least some of the gas that is released from the bottom opening enters the plurality of first cavities and is sheared by each outer edge of each of the plurality of first cavities.

8. The impeller of claim **7** that further includes a second top surface above the top surface.

9. The impeller of claim **8** wherein the second top surface is farther from the impeller bottom than the top surface.

10. A molten metal degasser including a motor, a drive shaft and the impeller of claim **7**.

11. The impeller of claim **1** wherein at least part of the passage is threaded.

12. The impeller of claim **1** wherein the top surface of the at least one cavity is the bottom of a top plate fastened to other structures that form the at least one curved side surface and the at least one open channel.

13. A molten metal degasser including a motor, a drive shaft, and the impeller of claim **8**.

14. The impeller of claim **8** wherein the top surface is the bottom surface of a top plate, and is fastened to other structures that form the concave curved side surfaces, cavity openings, and outer edges.

15. The impeller of claim **14** wherein the second top surface is the lower surface of a second top plate adhered to the top plate.

16. The impeller of claim **7** wherein the top surface has edges and the edges further shear the gas.

17. The impeller of claim **8** wherein the top surface is entirely under the second top surface.

* * * * *